



1949

**Regional level disparities and the driving forces of  
energy consumption and CO<sub>2</sub> emissions  
in the residential sector of Iran**

Thesis for the Degree of Doctor of Philosophy (PhD)

**Behnam Ata**

Supervisor: János Péntzes (Ph.D., Associate Professor)

UNIVERSITY OF DEBRECEN

Doctoral Council of Natural Sciences and Information Technology

Doctoral School of Earth Sciences

Debrecen, 2024

*Hereby I declare that I prepared this thesis within the Doctoral Council of Natural Sciences and Information Technology, Doctoral School of Earth Sciences, University of Debrecen in order to obtain a PhD Degree in Natural Sciences at Debrecen University.*

*The results published in the thesis are not reported in any other PhD thesis.*

*Debrecen, , 2024*

.....

*Signature of the candidate*

*Hereby I confirm that Behnam Ata candidate conducted his studies with my supervision within the Social geography and regional development planning Doctoral Program of the Doctoral School of Earth Sciences between 2020 and 2025. The independent studies and research work of the candidate significantly contributed to the results published in the thesis.*

*I also declare that the results published in the thesis are not reported in any other theses. I support the acceptance of the thesis.*

*Debrecen, , 2024*

.....

*Signature of the supervisor*

**Regional level disparities and the driving forces of  
energy consumption and CO<sub>2</sub> emissions  
in the residential sector of Iran**

Dissertation submitted in partial fulfillment of the requirements for the doctoral (PhD)  
degree in Earth Sciences

Written by: **Behnam Ata**      certified Energy Management

Prepared in the framework of the Doctoral School of Earth Sciences of the University of  
Debrecen,

Dissertation advisor: **Dr. János Péntzes**, associate professor

The official opponents of the dissertation:

Dr. ....  
Dr.....

The evaluation committee:

Chairperson: Dr.....  
Members: Dr.....  
Dr.....  
Dr.....  
Dr.....

The date of the dissertation defense: ..... 20...

# Table of contents

<b>1. Introduction.....</b>	<b>6</b>
1.1. An overview of CO <sub>2</sub> emissions .....	6
1.2. Aims and objectives of research .....	10
1.3. Structure of dissertation .....	11
<b>2- Literature review .....</b>	<b>13</b>
2.1. Worldwide context of CO <sub>2</sub> emission and energy trends .....	13
2.2. The residential sector and CO <sub>2</sub> emissions.....	17
2.3. Inequality in energy-related CO <sub>2</sub> emissions.....	20
2.4. Driving factors of CO <sub>2</sub> emissions in the residential sector .....	21
2.5. Energy consumption and CO <sub>2</sub> emissions in Iran.....	22
2.6. Energy subsidizing in the world and Iran .....	25
2.7. Methodologies for assessing CO <sub>2</sub> emissions and inequality.....	28
2.7.1. Most recent methods and findings in the research of CO <sub>2</sub> emissions and inequality .....	28
2.7.2. Bibliometric analysis of CO <sub>2</sub> emissions and energy research.....	31
2.8. Key aspects of the global and Iranian energy economy and CO <sub>2</sub> emissions. 33	
2.9. Energy production, consumption, pricing and markets .....	36
2.10. Iran’s situation in terms of energy market.....	40
<b>3. Methods and Materials.....</b>	<b>45</b>
3.1. Study area.....	45
3.2. Data.....	49
3.3. Inequality methods (Theil and Kaya Factor) .....	53
3.4. Trend analysis models.....	57
3.5. Econometric methods.....	58
3.6. Estimation methods.....	62
3.6.1. Static estimation models .....	62
3.6.2. Dynamic estimation models .....	64
<b>4. Results and discussion .....</b>	<b>66</b>
4.1. Descriptive results.....	66

4.2. Trend analysis .....	75
4.3. Analytic results .....	79
4.3.1. Kaya factor.....	86
4.4. Econometric results.....	88
4.4.1. Cross-sectional dependence result .....	89
4.4.2. Multicollinearity result .....	90
4.4.3. Results of the panel unit root test.....	90
4.4.4. Panel co-integration result .....	91
4.4.5. Static estimation.....	92
4.4.6. Dynamic estimation .....	95
4.5. Discussion .....	97
<b>5. Summary and Conclusion .....</b>	<b>103</b>
<b>6. Acknowledgement .....</b>	<b>105</b>
<b>7. Appendices.....</b>	<b>106</b>
<b>8. References.....</b>	<b>112</b>

# 1.Introduction

## 1.1. An overview of CO<sub>2</sub> emissions

The unequal distribution of CO<sub>2</sub> (carbon dioxide) emissions among nations poses a significant challenge for creating a comprehensive global climate policy (Padilla & Serrano, 2006). The STEPS project predicts a rise in CO<sub>2</sub> emissions related to energy, reaching its highest point in the mid-2020s. Despite this peak, emissions will continue at a significant level, causing a rise in the Earth's average temperatures to approximately 2.4°C by the year 2100 (International Energy Agency, 2023). Emissions persistently add up in the atmosphere, leading to increased risks associated with climate change. From early 2019 to late 2022, over 140 gigatons of carbon dioxide (Gt CO<sub>2</sub>) emissions were attributed to the global energy system (International Energy Agency, 2023). Global warming is expected to rise further in the coming years (2021–2040) primarily due to the increased accumulation of CO<sub>2</sub> emissions in almost all projected scenarios and pathways modeled. In the near term, global warming is more likely than not to reach 1.5°C even under the very low GHG (Greenhouse Gases) emission scenario (Calvin et al., 2023). The rapid rise in carbon emissions has worsened the global greenhouse effect, resulting in more frequent extreme weather events that pose a severe threat to both the environment and human health. Halting the ongoing increase in carbon emissions is crucial not just for a green economic rebound but also for ensuring the sustainable progress of human society.

Newly industrialized economies have seen a significant surge in CO<sub>2</sub> emissions from energy use compared to industrialized nations since the 1990s. The decline in environmental quality has escalated to concerning levels, prompting heightened concerns about global warming and climate change (Mitić et al., 2023). Numerous factors contribute to global environmental decline and warming, such as economic and financial growth, energy usage, and population expansion (Ding et al., 2023). The elevation in CO<sub>2</sub> emissions, employment of renewable energy, supervision of municipal waste, economic growth, and globalization represent crucial interrelated matters occurring simultaneously (M. Wang et al., 2023).

Energy holds considerable importance for ongoing economic progress, nonetheless elements such as the heightened energy demand arising from the growth of the global population present threats. This upsurge in demand induces swift depletion of resources, specifically coal, natural gas, and oil, in conjunction with rising energy expenditures. Inadequate availability of energy may denote an inability to mitigate poverty and hasten development. Additionally, the burning of fossil fuels, which produces greenhouse gas emissions, is implicated in the phenomenon of global

warming (Rehman et al., 2023). Carbon dioxide is the key contributor to the greenhouse effect and has become a major focus of regulatory efforts. For instance, in 2019, global emissions amounted to 36.4 billion tons of CO<sub>2</sub> (W. Wang et al., 2023). While energy consumption and population levels in developed countries have remained relatively stable, developing nations such as China, India, and Thailand have seen significant increases in both areas over recent decades. Despite this, there remains a substantial disparity in energy consumption per capita between developed and developing countries, highlighting a global inequality in energy use. This gap may be influenced by factors such as embodied energy (Duan & Chen, 2018).

The global demand for energy has surpassed 170 million gigawatts (GW) annually, coinciding with a world population exceeding 7 billion in 2011. Considering the current population growth rate, it is anticipated that the global population will reach 9 billion by the end of 2040, leading to a projected 27% energy deficit. Presently, 1.2 billion people lack sufficient access to energy resources, posing a significant challenge in achieving the Sustainable Development Goals (SDGs) by 2030. However, it is important to note that the expanding energy deficit cannot be solely attributed to population growth; the increasing demand for energy in digitalized civilization, driven by rising per capita income and innovations, also plays a substantial role (World Bank, 2019).

Carbon emissions primarily stem from industries, transportation, and buildings. Specifically, the building sector (refers specifically to residential buildings) contributes to 36% of the world's final energy usage and 37% of CO<sub>2</sub> emissions related to energy consumption (United Nations Environment Programme, 2021). Carbon intensity represents the correlation between carbon emissions and GDP (Gross Domestic Product), showcasing how pollutants relate to economic advancement. A greater carbon intensity signifies a higher emission of CO<sub>2</sub> per unit of economic productivity (H. Chen et al., 2022). Certainly, the alteration in carbon emission intensity is influenced by various factors like the composition of energy sources, industrial setup, and technological advancements, among others. Hence, formulating mechanisms to diminish carbon emissions' intensity often necessitates an acknowledgment and equilibrium of divergent policy mechanisms (H. Chen et al., 2022).

Within this context, the European Union (EU) has emerged as a crucial international entity in addressing climate change issues. The European Commission has designated this mission as a main priority, intending to reach carbon neutrality across the EU by the year 2050 (Duarte et al., 2021). For a European climate blueprint to realize carbon neutrality by 2050, it must rapidly reorient the economy towards a

novel developmental path that secures substantial social and political endorsement from the beginning (Wolf et al., 2021). In 2015, the introduction of the SDGs and the Paris Climate Agreement marked the start of a worldwide effort. However, many nations continue to face challenges in reaching the intended goal of carbon neutrality, aiming for a sustainable economy with minimal CO<sub>2</sub> emissions (Shao et al., 2021). Over the past decade, there has been a growing concern among policymakers in various European countries and at the European level regarding the challenges faced by certain households in accessing and affording an adequate amount of energy services (European Economic and Social Committee, 2010, 2013).

Investigating the significant fluctuations in CO<sub>2</sub> outputs within the building industry of China becomes crucial for understanding spatial inequalities and their foundational reasons. Grasping these distinctions holds importance for promoting equitable regional advancement and curbing greenhouse gas discharges efficiently (H. Li et al., 2021). Energy inequality is considered a more effective measure of inequality compared to income inequality because it holds the ongoing benefits derived from long-lasting goods and services (Wu et al., 2017).

Establishing a climate-neutral society faces a major hurdle: growing disparities in access to energy. Building a future free of climate impact is urgent. It means striking a balance between progress, technology, nature, people's welfare, and personal growth. Europe's push for a green agenda is centered on this transition, echoing the promises of the Paris Agreement. It acknowledges the worldwide urgency of battling climate change and stresses the vital role of reducing inequality to meet Sustainable Development Goals. Addressing energy disparities and ensuring fair access to clean energy is key to secure everyone's well-being and a high quality of life (Volodzkiene & Streimikiene, 2023). As the integration of energy markets is in progress, it is crucial to examine the general patterns in both energy consumption and energy intensity. It is important to determine whether the trends in each country align with the Sustainable Development Goal 7 (SDG7) (Bianco et al., 2021). To significantly decrease GHG emissions and address climate warming, it is imperative to transition towards sustainable consumption. This is particularly crucial in Latin American and Caribbean (LAC) nations where biodiversity is susceptible to the impacts of climate change. Failure to do so could lead to irreversible ecosystem damage and socio-economic crises, with potential economic costs in the region reaching up to 5% of the GDP by the year 2050 (United nations, 2015; Welch & Southerton, 2019).

Several factors have contributed to the rise in CO<sub>2</sub> emissions in Iran's building sector over the past 50 years. Firstly, the recent decades have seen an increase in energy consumption due to rapid population growth and urbanization (Nejat et al.,

2015). Additionally, the dominance of fossil fuels, particularly natural gas, in Iran's energy supply chain is attributed to the country's extensive fossil fuel reserves. The residential sector is a major contributor to energy consumption, accounting for one-third of the total final consumption, thus making it the largest energy-consuming sector in the country (IEA, 2014; Mohammadnejad et al., 2011). Furthermore, energy inefficiencies are exacerbated by factors such as international sanctions related to nuclear energy, high financial inflation rates exceeding 40%, and bank interest rates above 18%. The absence of low down payment loan programs, continued energy subsidies for non-renewable sources, and low energy prices also play a significant role. Additionally, the lack of mandatory energy codes and standards for buildings compounds the issue (Kazemi, 2018).

However, around 2008, there was a significant reduction, followed by a fluctuating trend in CO<sub>2</sub> emissions from the building sector in Iran. Moreover, the trend highlights the importance of conducting research at the regional level on fluctuations in CO<sub>2</sub> emissions and identifying the factors contributing to emissions in the building sector. The substantial energy consumption in building sector prompted the government to implement immediate actions over the past decade to curb this trend. In 2009, the government opted to increase energy prices and progressively reduce energy subsidies. This policy led to a decline in demand, resulting in a decrease in the growth rates of oil and electricity consumption to -15% and -8%, respectively (Nejat et al., 2015).

The initial Building Energy Code (BEC) was launched in the early 1990s under the title Issue 19, with its final version being updated in 2005. This prescriptive BEC applies to all buildings across Iran. Initially voluntary, the code was made mandatory for the capital city in 2004, for major cities in 2007, and for smaller cities by 2011 (Office of Promoting and Development of National Building Regulations., 2004; R. Khalaji, 2010). Compared to successful Building Energy Codes BECs globally, Iran's BEC has encountered several challenges. These include inadequate oversight by authorities, reliance on an outdated prescriptive approach rather than more adaptable performance-based methods, and the use of traditional construction techniques rather than modern industrial systems. Additionally, there is a prevalent public perception that adhering to the BEC will increase construction costs, a low rate of renovation for older buildings, and a lack of focus on integrating modern renewable energy sources into the BEC (Nejat et al., 2015).

## 1.2. Aims and objectives of research

The thesis aims to examine and evaluate inequalities and the factors influencing energy-related CO<sub>2</sub> emissions in Iran's residential sector from 2001 to 2019. To accomplish this goal, the following goals need to be addressed:

1. To analyze the regional disparities in CO<sub>2</sub> emissions and various kinds of fuels in the residential sector of Iran.
2. To investigate the effects of different factors such as climate, socioeconomic, energy on CO<sub>2</sub> emissions among the provinces of Iran.
3. To analyze the trend in energy consumption and CO<sub>2</sub> emissions at the regional level in Iran.
4. To address the current policies regarding regional disparities in CO<sub>2</sub> emissions and energy consumption in the residential sector of Iran.
5. To provide recommendations from developed countries on reducing CO<sub>2</sub> emissions in the residential sector of emerging economies.

The dissertation consists of three major research parts to achieve the aims of the investigation. The first part focuses on the issue of inequality at the regional level in the residential sector of Iran. Using the Theil index and Kaya factors, the main factors contributing to inequality among the provinces of Iran in terms of CO<sub>2</sub> emissions and energy consumption are determined. The analysis considers the period from 2001 to 2017. The provinces are grouped into four categories to assess within-group and between-group inequality in terms of CO<sub>2</sub> emissions and energy consumption. Based on population and income, the provinces are decomposed into within-group and between-group categories to identify differences at the regional level and to assess existing policies aimed at reducing CO<sub>2</sub> emissions.

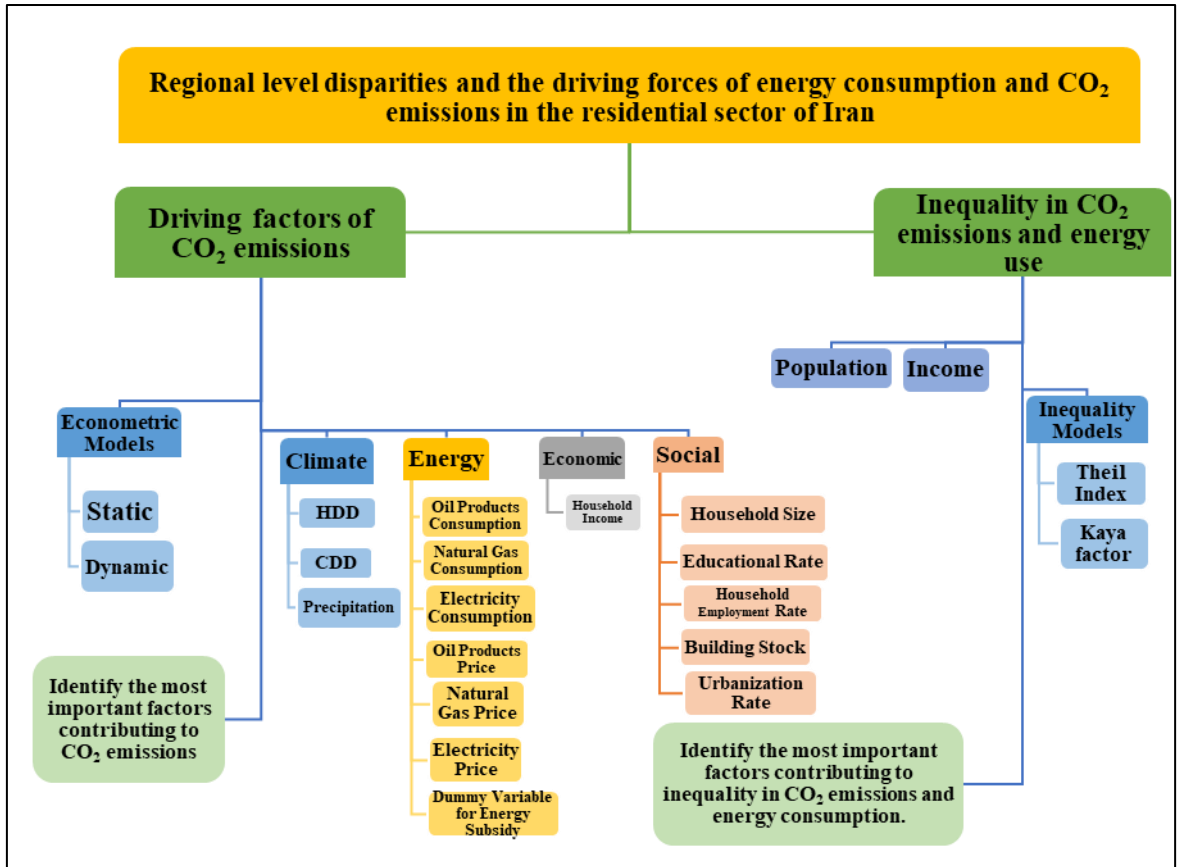
The second part addresses the driving factors of CO<sub>2</sub> emissions at the regional level in the residential sector of Iran. This research employs econometric models, including both static and dynamic models, using data from 2001 to 2019. Various variables, such as climate, energy, socio-economic factors, and energy subsidy reforms (considered as a dummy variable), are included. Both static and dynamic models are applied to determine the effect of time on CO<sub>2</sub> emissions. Provinces, based on their different circumstances, reflect completely different factors in terms of CO<sub>2</sub> emissions. Therefore, understanding regional-level CO<sub>2</sub> emissions and energy consumption is essential for reducing CO<sub>2</sub> emissions and is necessary for policymakers in terms of reforming energy subsidies.

The third part evaluates trend analysis with consideration of price and subsidy reforms. This research investigates time series data from 2001 to 2019 in the residential sector of Iran, using the Mann-Kendall test for the provinces of Iran.

The primary innovation of my investigation lies in its examination of regional disparities in energy consumption and CO<sub>2</sub> emissions, as well as the regional breakdown of CO<sub>2</sub> emissions within the household sector topics that have not been previously explored. This research aims to provide a foundation for academic investigations, paving the way for the development of precise and effective CO<sub>2</sub> emission reduction policies for the household sector over time.

### **1.3. Structure of dissertation**

The dissertation includes five chapters. The first chapter is about the introduction and aims of the research, presenting the background and idea regarding CO<sub>2</sub> emissions related to energy on a global scale and in the residential sector of Iran. The second chapter focuses on the literature review and theoretical background of the investigation to support the research aims. The third chapter consists of the study area and methodology, which includes the inequality method (Theil index) and Kaya factor. Additionally, econometric models, including static and dynamic methods, are discussed. Trend analysis, incorporating the Mann-Kendall has also been applied. This chapter further represents data analysis and the types of data used which most of data used from annual energy balance sheet and national census in Iran. The fourth chapter presents the results and discussion, divided into three parts. The first part addresses inequality, the second part discusses the driving forces of CO<sub>2</sub> emissions in the residential sector of Iran, and the last part includes the results of the trend analysis. Finally, the last chapter consists of the conclusion and policy implications in light of the new findings. Figure 1 represent the flowchart of research structure.

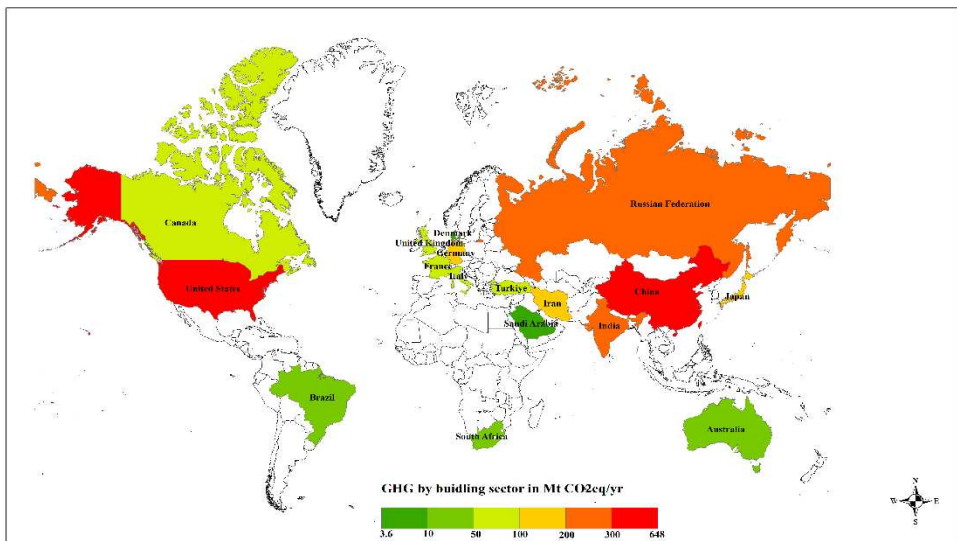


**Figure 1.** The structure of the dissertation (created by the author)

## 2- Literature review

### 2.1. Worldwide context of CO<sub>2</sub> emission and energy trends

The increase in greenhouse gas absorption, namely the rise in carbon dioxide (CO<sub>2</sub>) in the global atmosphere from various sources, is the cause of the concerns associated with global warming. During the years, the Earth's surface temperature has been rising daily (D. Li et al., 2024). The overview of global CO<sub>2</sub> emissions and energy issues due to climate change and crises is critical. Therefore, different nations worldwide must take action to reduce CO<sub>2</sub> emissions and reach net zero emissions. In the USA, CO<sub>2</sub> emissions in the power sector are projected to be 50% lower by 2030 compared to today. The updated nationally determined contribution aims to reduce GHG emissions by 50-52% by 2030 from 2005 levels, with a national target to reach net zero GHG emissions by 2050. In Latin America and the Caribbean, half of the region accounts for around 65% of the GDP and 60% of its energy-related CO<sub>2</sub> emissions (see Figure 3). The European Union's Fit for 55 program aims to increase the minimum energy performance standards for existing buildings and requires all new buildings to be zero emissions by 2028. According to Figure 4, the industrial sector, with 34.6%, is the highest contributor to CO<sub>2</sub> emissions. The transport sector, with 20.6%, has the second highest CO<sub>2</sub> emissions globally from 1970 to 2022. The building sector, with 12.5%, is also one of the highest CO<sub>2</sub>-emitting sectors in the world (International Energy Agency, 2023).



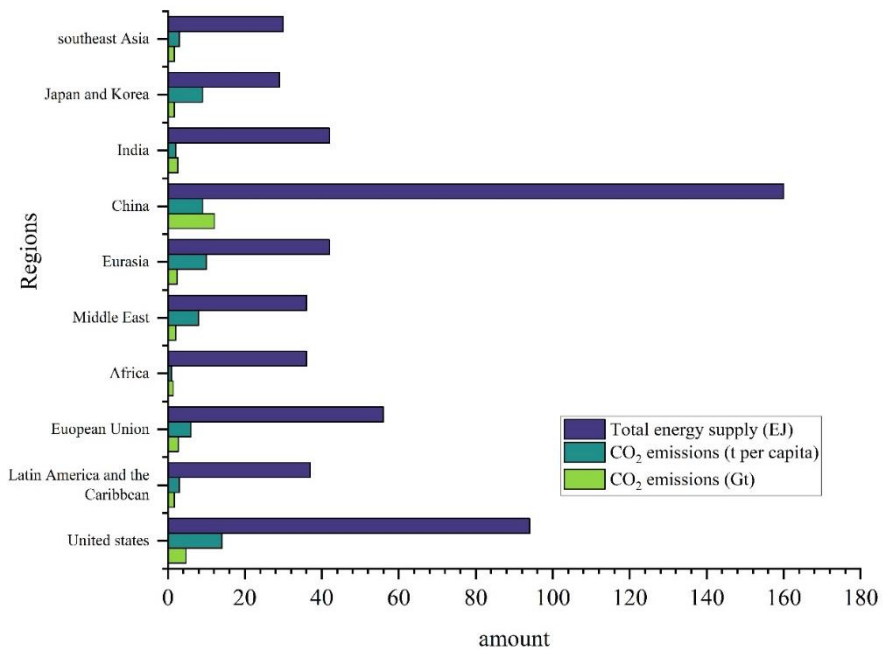
**Figure 2.** Values in GHG in building sector and country in Mt CO<sub>2</sub>eq/yr in 2023 (JRC, 2023).

In Africa, more than 40% of the population lacks access to electricity, and 70% lack access to clean cooking facilities. The Middle East, among emerging market and developing economies, shows a wide range of income and energy consumption levels. Countries like Saudi Arabia and the United Arab Emirates have high per capita incomes and energy consumption, whereas Yemen and Syria are at the lower end. This region is expected to have the second-largest oil demand growth and the largest natural gas demand growth of any region, with a 30% increase in annual CO<sub>2</sub> emissions by 2050.

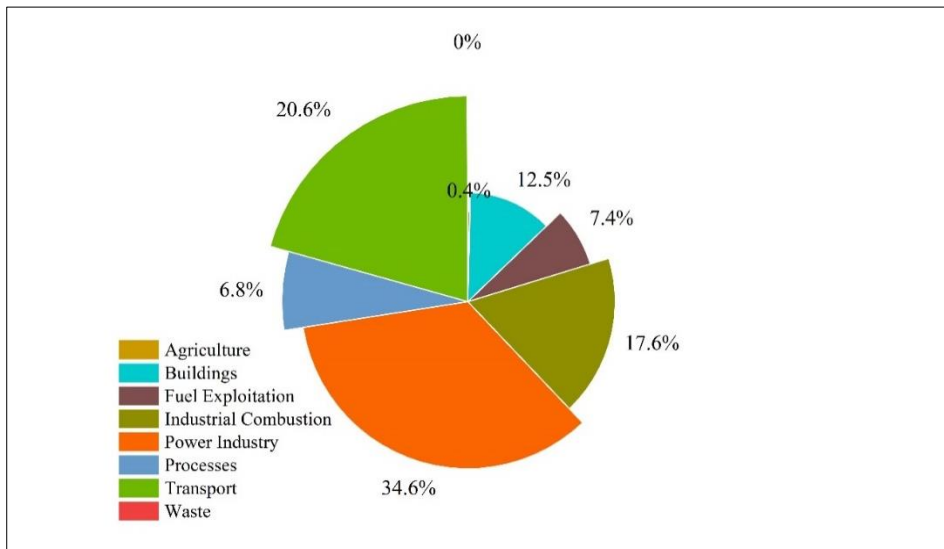
The countries of the Caspian region and Russia, with a total energy supply of 175 Gigajoules (GJ) per person, per capita energy consumption is high compared to the global average of about 80 GJ per person and 60 GJ per person in other emerging markets and developing economies. This high energy consumption partly reflects cold winters but also stems from widespread inefficiency in energy supply and use. Energy-related CO<sub>2</sub> emissions in Caspian region and Russia were roughly 2.4 Gt in 2022.

China is the world's largest producer and consumer of coal, and a major consumer of oil and gas, making it the largest CO<sub>2</sub> emitter globally (see Figure 2), accounting for one-third of the global total. Its total CO<sub>2</sub> emissions were 12.1 Gt in 2022, mainly from the use of coal in electricity generation and industry. However, China is also the largest user of many clean energy technologies. Since 2000, India has provided electricity to 810 million people and clean cooking access to 655 million people, although 430 million people still use traditional biomass today. India is entering a dynamic new phase in its energy development, marked by a long-term net zero emissions ambition, increased regulatory sophistication, a focus on clean energy deployment, and the creation of a domestic clean energy technology supply chain.

Japan and Korea continue to map out secure pathways to achieve their net zero emissions pledges by 2050. However, it remains challenging to decarbonize large industrial economies that have historically relied heavily on imported fossil fuels. In Southeast Asia, the continued reliance on fossil fuels leads to the largest absolute growth of CO<sub>2</sub> emissions of any region in the world (International Energy Agency, 2023).



**Figure 3.** CO<sub>2</sub> emissions and total energy supply in world regions. Created by the author based on International Energy Agency (2023).

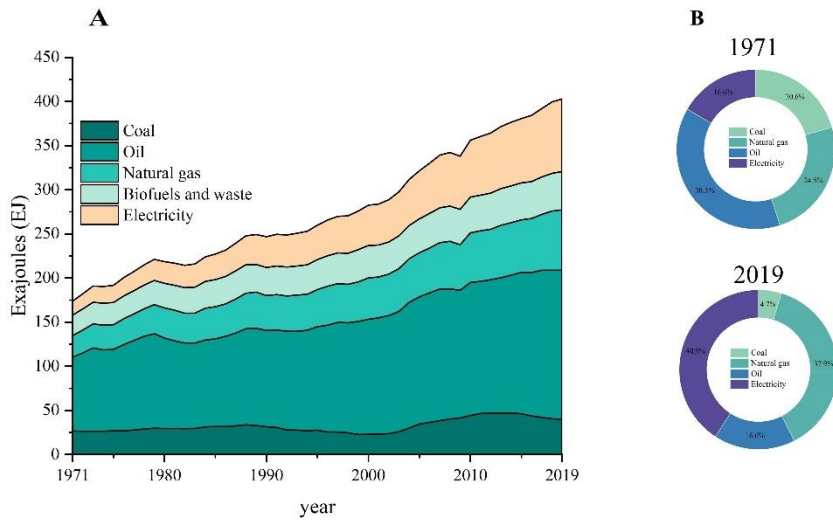


**Figure 4.** CO<sub>2</sub> emissions from different sectors average from 1970 to 2022 in global scale. Created by the author based on European Commission (2023).

The overview of different regions highlights the importance of regional planning on a global scale for controlling and reducing CO<sub>2</sub> emissions. Each region faces unique challenges with climate change and CO<sub>2</sub> emissions reduction. It is crucial to increase support for regions that lack access to energy, while emerging economies and regions with high fossil fuel consumption need to control and reduce their consumption. Over the past few decades, there has been an increasing trend of central governments around the world delegating their responsibilities for environmental policies to local governments (Khan et al., 2021). A greater level of fiscal decentralization is believed to be more effective in promoting pollution control and reducing CO<sub>2</sub> emissions, often referred to as a ‘race to the top’. Advocates of this perspective argue that fiscal decentralization allows local governments to improve the efficiency of resource allocation, better assess regional pollution levels, and respond more accurately to the preferences and needs of their residents (Millimet, 2003; Mu, 2018). According to the IEA (2023) report, certain regional policies have already been included where they substantially impact the global energy landscape. Examples include regional carbon markets and energy efficiency standards implemented in large provinces or states. These policies can significantly influence global emissions by encouraging more sustainable energy practices and incentivizing carbon reduction across borders. These policies reflect the broader importance of regional planning in addressing climate goals (International Energy Agency, 2023).

In two ways, the residential energy (RE) sector is now essential to implementing quick emission reductions. First, the residential sector accounts for 17% of world CO<sub>2</sub> emissions and about 25% of global energy use (IEA, 2016) and therefore directly and significantly impacts the global environment (Nejat et al., 2015). Energy policies may be more effective than those in other sectors because residential environmental rules are hard to transfer to other nations (Pablo-Romero et al., 2017).

Figure 5 (A) shows global energy consumption, where oil, natural gas, and electricity make up the majority of consumption. Although coal does not play a major role in overall energy consumption, it remains a significant fuel for electricity generation. Also Figure 5 (B) depicts the share of different energy sources among households. In 1971, coal accounted for 20.6% of household energy consumption, but this figure decreased to 4.7% by 2019. During the same period, the share of natural gas and electricity consumption increased due to the energy transition. Conversely, oil consumption in the household sector has significantly decreased.



**Figure 5, A**, Energy final consumption across world by source and, **B**, share of different sources in residential sector in 1971 and 2019. Created by the author based on International Energy Agency (2021).

Although modern energy carriers from renewable resources have been produced for several decades, in some regions, renewable sources like biomass (e.g., firewood) are still utilized in their most basic form to fulfill energy needs, such as cooking and heating in homes. It is estimated that approximately 2.6 billion people worldwide rely on these traditional methods (Masera et al., 2015). Around half of the population in developing countries relies on burning solid biomass to fulfill their essential energy needs (Cutz et al., 2017). In Iran, only three provinces of Golestan, Mazandaran, and Gilan have permission to produce wood products. These provinces produced 115 thousand cubic meters of wood. Forest fuel is used for personal purposes, including cooking, heating, and providing hot water for homes. However, due to the lack of accurate estimates of the consumption of these resources in Iran, conducting an annual census for these energy carriers is not currently feasible (Ministry of Energy of Iran, 2021). Rural households in northeast, south, and southwest Iran are more inclined to use biomass compared to those in other regions (Rahmani et al., 2020).

## 2.2. The residential sector and CO<sub>2</sub> emissions

A precise estimate of how much energy buildings will consume and the resulting CO<sub>2</sub> emissions (reflecting the operational energy usage and emissions) serves as the foundation for creating policies aimed at conserving energy and reducing emissions within the building industry (Y. Y. Guo, 2022; Tang et al., 2021). In 2015, 90 nations took steps to tackle emissions linked to buildings or enhance energy efficiency as part

of their nationally determined contributions to the Paris Agreement (Zhao et al., 2022).

In 2020, the global annual growth rate in the buildings and construction sector decreased by approximately 4% compared to 2019. This decline in market expansion was primarily due to the significant influence of the worldwide pandemic on construction operations. Lockdowns affected labor availability, reduced demand for new construction, slowed down both public and private projects, and caused disruptions in the supply chain (United Nations Environment Programme, 2021). In September 2013, China's State Council introduced its most stringent plan yet, aiming to combat severe air pollution and enhance public health. Since then, numerous bold steps have been taken to cut down on fossil fuel use and the pollutants it generates. Residential emissions, responsible for a significant 33% of primary PM (Particulate Matter) and a major part of air pollution, have been a focus in these efforts (Q. Wang et al., 2023). Presenting factual data on greenhouse gas emissions in various sectors motivates the creation or adaptation of strategies and policies aimed at mitigation (Altouma et al., 2024). The choice of building materials and conditions plays a pivotal role in enhancing energy efficiency and decreasing CO<sub>2</sub> emissions. As a result, implementing regional planning that is in line with each province's climate conditions can significantly improve building energy efficiency (Ata et al., 2023). One of the primary legislative attempts to reduce the use of fossil fuels and global warming is energy efficiency, which is receiving increasing attention from the government and international organizations (Danish et al., 2019). Due to changes in climatic conditions, such as rising temperatures and an increase in the frequency of extreme heat events, building designers now face a challenge that they have never encountered before: creating structures that can perform properly throughout the duration of their uses.

Energy-saving and energy storage technologies play a key role in reducing CO<sub>2</sub> emissions by boosting energy system efficiency and enabling the use of renewable energy sources. Increasing energy efficiency in buildings and industrial operations can greatly lower overall energy demand, which helps reduce greenhouse gas emissions (Prol-Godoy et al., 2024). Furthermore, energy storage options, such as batteries and thermal storage, allow for the capture and use of surplus renewable energy, lessening dependence on fossil fuels during times of high demand (Mancinelli et al., 2023). Together, these approaches not only advance the shift toward a low-carbon economy but also strengthen energy resilience and security (Gerres et al., 2023). As countries work toward their climate objectives, implementing energy-saving and storage solutions will be essential for building sustainable energy systems (Kulczycka et al., 2023).

Kamal et al (2019), explored the potential of energy efficiency policies to reduce energy consumption in Qatar's rapidly expanding building sector, which has doubled in size over the past 15 years. Using a system dynamics model developed with the Venty™ tool, it forecasts energy consumption across 28 building types and evaluates seven policies focused on renovation and new construction. Indicate that constructing energy-efficient buildings and renovating older ones every 10 years can save over 4700 GWh of electricity and reduce CO<sub>2</sub> emissions by 2.3 million tons by 2050. Importantly, efficient new construction offers twice the savings compared to renovation policies, emphasizing the need for developing countries to prioritize energy-efficient building designs over retrofitting older structures.

Balaras et al (2007) in European Union (EU) member states, the existing building stock is responsible for more than 40% of the total final energy consumption, with residential buildings accounting for 63% of the energy used within the building sector., making energy efficiency improvements critical for reducing CO<sub>2</sub> emissions and energy import dependency. They evaluated energy conservation measures (ECMs) for Hellenic residential buildings, based on a comprehensive assessment of the national building stock despite limited primary data. Effective ECMs include external wall insulation (33–60% energy savings), weatherproofing openings (16–21%), double-glazed windows (14–20%), boiler maintenance (10–12%), and solar water heating systems (50–80%). These measures support compliance with the Kyoto Protocol and the European Energy Performance of Buildings Directive (EPBD).

In addition to the average and extreme climates of nowadays, the performance evaluation of newly constructed or refurbished structures should take into account the extreme occurrences and predicted future climates (Machard et al., 2024). The two main methods now used for energy conversion and the reduction of GHG emissions are utilizing sustainable and renewable energy systems and improving the efficacy and efficiency of fossil fuel energy systems (Kenny et al., 2010).

The amount of energy saved by implementing energy-efficient policies and technologies into practice depends on how they are used and how the money saved as a result is put to use. Nevertheless, despite the obvious financial and ecological benefits of energy-efficient buildings, the adoption of energy-saving technology and practices in these structural environments is frequently slower and more restricted (Belaïd & Mikayilov, 2024).

### **2.3. Inequality in energy-related CO<sub>2</sub> emissions**

The variations in emissions per person among European Union countries are crucial in setting distinct mitigation policy goals. These differences stem from factors that have developed uniquely in each country (Padilla & Duro, 2013). Due to varying geographical, economic, social, climatic, and natural factors impacting energy usage, it is essential to conduct localized studies to address disparities in CO<sub>2</sub> emissions. Such investigations would pinpoint key factors contributing to inequality in household energy consumption, aiding in better planning and management. While national policies have targeted emissions and energy usage, a regional-level analysis is crucial for formulating impactful policy recommendations to address consumption and emission disparities effectively (Ata et al., 2022).

However, inequality in energy-related CO<sub>2</sub> emissions across world countries varies based on different factors. Over time, there is a growing disparity across Indian states in terms of CO<sub>2</sub> emissions, resource availability, and economic growth. For example, from 2013 to 2021, the northern region's population increased six times over that of the northeastern region, despite the northern region's CO<sub>2</sub> emissions being almost 32 times greater (Liu et al., 2024).

For China to reach carbon peaking and carbon neutrality, efficient provincial-level emission reduction plans are essential. As a result, it's critical to precisely identify the temporal and spatial patterns of carbon intensity (CI) in each province as well as the variables influencing them. This forms the basis for putting carbon emission reduction plans into action (R. Li et al., 2023). Carbon inequality poses a significant challenge impacting both economic progress and societal well-being. In the era of globalization, the robust growth of regional trade has sped up the flow of goods and services, leading to more frequent transfer of carbon emissions across regions (Sun et al., 2020; Z. Wang et al., 2019). Significant regional differences occur in energy use, and varied geographic conditions and social development levels result in different patterns of carbon emissions. Notably, different locations have varied levels of energy consumption, and due to geographical variables and differences in societal development, different patterns of carbon emissions exist (Mi et al., 2020). While analyzing the differences in household carbon emissions caused by energy use, the particular patterns of energy consumption should be taken into account. A more realistic depiction of the changes in end-use carbon emissions within energy consumption patterns and income disparities across areas can be obtained by analyzing the breakdown of this inequality (L. Chen et al., 2023).

## 2.4. Driving factors of CO<sub>2</sub> emissions in the residential sector

Many studies have focused on the driving factors of CO<sub>2</sub> emissions in the residential sector worldwide. Some studies have concentrated on a few variables related to CO<sub>2</sub> emissions, while others have considered multiple factors to understand different aspects of CO<sub>2</sub> emissions in the residential sector. Global domestic energy expenditure rose by 14%, primarily driven by population growth, urbanization, and economic development in emerging countries (Nejat et al., 2015).

In China, residential energy consumption and CO<sub>2</sub> emissions are on the rise, with notable differences across provinces and between urban and rural areas due to varying economic development levels, energy use behaviors, and climatic conditions (Guan et al., 2023). The study by Mitić et al (2023) examined the causal relationships between CO<sub>2</sub> emissions, economic growth, available energy, and employment in eight South-Eastern European countries from 1995 to 2019.

Another study Altouma et al (2024) investigated the relations among CO<sub>2</sub> emissions and various economic variables in the context of Saudi Arabia's Vision 2030. The study by Soltani et al (2020) presented six variables about consumption, energy sources, and demography that were included in the structural model. These variables were household age, size, gender, income quintile, and level of education. Another study by Büchs and Schnepf (2013) realized that these connections vary considerably between emission areas. Whereas all types of emissions rise with expenses. Elderly families, those with poor incomes, and those without jobs are more likely than households belonging to other categories to have high home energy emissions.

The research by Meangbua et al (2019) studied the effects of demographic and socioeconomic variables on Thailand's residential CO<sub>2</sub> emissions. The study by Fan et al (2019) examined household carbon emissions are significantly influenced by both personal circumstances and home energy use. This study is relevant to policy because the distribution of mitigating measures may vary depending on the region in which they are implemented if certain household types are anticipated to have higher emissions in some locations than in others. Wang et al (2018) applied a geographically weighted regression (GWR) model to explore how urbanization, energy intensity, energy structure, and income affect household CO<sub>2</sub> emissions (HCE) across different provinces in China. The findings reveal significant spatial variations in HCE. The impact of urbanization on emissions increased from southeastern to northwestern China from 2000 to 2015. Energy intensity generally had a positive effect on HCE, though it showed some negative effects in specific years. The use of natural gas and electricity generally reduced HCE, while income

consistently contributed to its growth, with its effect becoming more pronounced over time.

Nonetheless, examining the literature makes it clear that a variety of factors, including GDP, economic growth, the use of gas, energy choices, energy costs, and consumption have an immense impact on CO<sub>2</sub> emissions. The majority of these studies do not consistently analyze all of the above-mentioned elements; instead, they only consider two, three, or at most four aspects. However, research conducted on a regional scale is insufficient and does not take into account all variables. In the meantime, human and natural variation within a region are the most significant determinants, and these vary greatly throughout regions. As a result, this study closes the prior research gap by taking into account all relevant elements and doing so regionally in Iran to attain sustainability and lower CO<sub>2</sub> emissions. Additional research is necessary to fully understand the causes and variables influencing CO<sub>2</sub> emissions in relation to the impact of emissions on climate change. One of the highest emissions of CO<sub>2</sub> occurs in the household sector.

Various research approaches have been employed in various projects to investigate the factors influencing CO<sub>2</sub> emissions in the household sector. The majority of studies indicate that energy consumption is one of the primary causes of CO<sub>2</sub> emissions; in the meantime, socioeconomic and demographic factors influence CO<sub>2</sub> emissions differently in each of the world's nations, and urbanization is yet another significant contributor.

## **2.5. Energy consumption and CO<sub>2</sub> emissions in Iran**

According to the statistics by Ministry of Energy (2021) final per capita energy consumption in the agriculture sector of Iran is 3.4 times higher than the global average. In the household (public and commercial) sector, it is 2.1 times higher, in the transport sector it is 1.7 times higher, and in the industrial sector, it is 1.6 times higher than the global average. Final per person energy consumption in 2014 and 2022 is 14.4, and 17.1 barrel equivalent of crude oil. Figure 6 depicts the share of CO<sub>2</sub> emissions from different sectors in Iran from 2010 to 2021, highlighting that power plants, transport, and the building sector constitute the majority of CO<sub>2</sub> emissions in the country. The power plant sector exhibited a sharp increase in emissions in 2014. Additionally, from 2017 onwards, most sectors displayed an upward trend in CO<sub>2</sub> emissions. Hajilary et al (2018) investigated the impact of socio-economic factors on CO<sub>2</sub> emissions in Iran was assessed using factorial design to identify key variables and their relationships with carbon emissions. Their results revealed that CO<sub>2</sub> emissions are significantly influenced by energy expenditure,

including its price, non-oil GDP which is GDP not derived from oil-related activities, citizen rate, and foreign direct investment (FDI), showing linear relationships with these factors. For the first time, the partial least squares (PLS) model was utilized to explore associations between these significant factors. The findings from the latent variable model indicated that lower energy expenditure, with a coefficient of 0.87, leads to reduced CO<sub>2</sub> emissions. Additionally, FDI and citizen rate were identified as two highly significant drivers, with shares of 13% and 4% respectively, impacting CO<sub>2</sub> emissions through opposing relationships. Energy costs and non-oil GDP play a minor role in explaining CO<sub>2</sub> emissions.

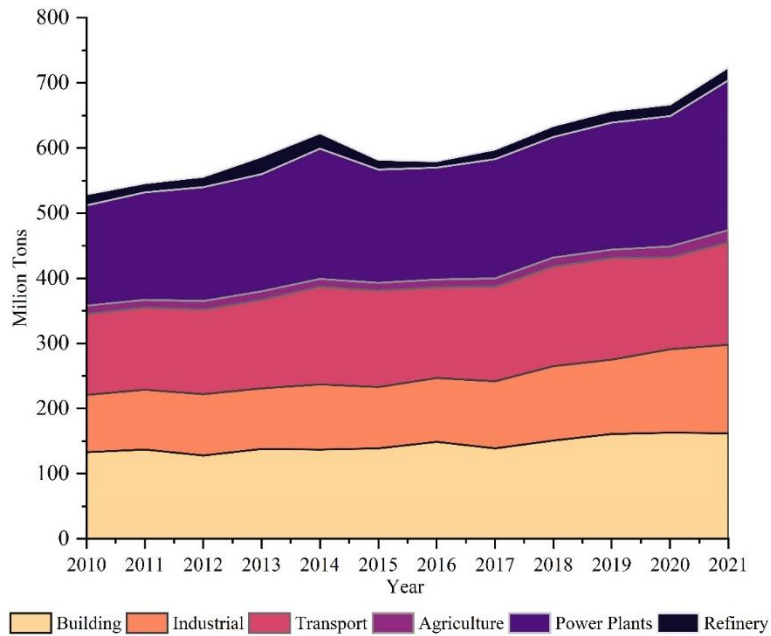
Hafeznia et al (2017) examined Iran's natural gas industry as a key component in the country's transition to a low-carbon economy to meet its greenhouse gas reduction commitments. Iran holds vast natural gas reserves, estimated at 33,500 billion cubic meters (bcm) by 2015, with the South Pars field being the largest. Despite high production capacity and widespread natural gas use in urban and rural areas, challenges such as growing domestic demand, energy losses in residential and commercial sectors, and inefficiencies in industry and power generation hinder the full potential of natural gas. Overcoming these challenges could enable natural gas to play a crucial role in reducing CO<sub>2</sub> emissions and facilitating Iran's transition to renewable energy. Mirzaei and Bekri (2017) developed a system dynamics model to predict energy consumption and CO<sub>2</sub> emissions trends in Iran from 2000 to 2025. The model incorporates various energy policy factors and their impact on environmental quality. It forecasts that Iran's total energy consumption will reach 2150 in 2025, up from 1910 in 2010, reflecting a 4.3% annual increase. Similarly, CO<sub>2</sub> emissions are expected to grow by 5% annually, reaching 985 million tons by 2025. The study also explores policy scenarios based on energy intensity reduction, showing potential CO<sub>2</sub> emission reductions of 12.14% with a 5% energy intensity cut and 17.8% with a 10% reduction. These results offer valuable insights into Iran's future energy and emission outlooks. Farajzadeh and Nematollahi (2018) examined the increasing energy intensity in Iran, which is among the highest globally, by analyzing the factors contributing to its rise, including efficiency and structural changes. Using regression analysis, the research identifies a non-linear relationship between energy intensity, income, and the capital-output ratio, with no significant impact from trade or energy prices. The study also highlights that urbanization could reduce energy intensity, and forecasts energy intensity and its components with minimal error (less than 0.35%). The results show that artificial neural networks (ANNs) are more accurate in predicting efficiency and structural change, while regression models are better at forecasting overall energy intensity.

According to the latest published energy balance sheet in 2021 Table 1, the final energy consumption across various sectors in Iran varies significantly by fuel type. In terms of oil fuels, the transport sector is the largest consumer with 42.3 million tons of crude oil equivalent (MTCO), followed by the non-energy sector at 10.2 MTCO, the industrial sector at 4.5 MTCO, the building sector at 3.9 MTCO, and agriculture at 2.9 MTCO. For natural gas, the building sector leads with 59.9 MTCO, the Industrial sector follows with 47.3 MTCO, and the transport, agriculture, and non-energy sectors consume 7.5, 3.9, and 8.6 MTCO respectively. Coal fuel usage is minimal, with the building sector at 0.1 MTCO, the industrial sector at 0.3 MTCO, and the non-energy sector at 0.8 MTCO. Electricity consumption is notable in the building sector at 11.8 MTCO, the industrial sector at 8.6 MTCO, in the agriculture sector at 3.5 MTCO, and the transport sector at 0.1 MTCO. The household sector's biomass consumption is very low, amounting to only 0.1 MTCO. In summary, natural gas and electricity were the most commonly used energy sources in the household sector in 2021 (Ministry of Energy Iran, 2021).

**Table 1.** Iran final energy consumption among different sectors in 2021

<b>Sector</b>	<b>Household</b>	<b>Transportation</b>	<b>Industrial</b>	<b>Agriculture</b>	<b>Non-energy</b>
<b>Year</b>					
Oil products	3.9	42.3	4.5	2.9	10.2
Natural gas	59.9	7.5	47.3	3.9	8.6
Coal	0.1	-	0.3	-	0.9
Biomass	0.1	-	-	-	-
Electricity	11.8	0.1	8.6	3.5	-

Reference: (Ministry of Energy of Iran, 2021)



**Figure 6.** CO<sub>2</sub> emissions from different sectors in Iran from 2010 to 2021. Created by author on the basis of data from the Ministry of Energy (2021).

## 2.6. Energy subsidizing in the world and Iran

In 2022, global subsidies for fossil fuel consumption topped \$1 trillion for the first time, marking a notable rise. This sharp increase came about because of disruptions in energy markets, which caused international fuel prices to soar above the actual costs for many consumers. The subsidies in 2022 were double those of the previous year, which were already nearly five times higher than in 2020. This dramatic jump was largely due to the global energy crisis sparked by Russia's invasion of Ukraine (IEA, 2023).

The IEA has long pushed for the removal or at least the reduction of fossil fuel subsidies. These subsidies distort markets, send misleading price signals to consumers, increase budget deficits in developing countries, and hinder the shift to cleaner renewable energy sources. The increase in subsidies is especially troubling at a time when there should be a focus on reducing wasteful consumption and speeding up the transition to clean energy. While reforming these subsidies is politically challenging, it is crucial for both economic and environmental reasons. In 2022, Russia was the biggest contributor to fossil fuel subsidies (Figure 7), followed by Iran and China (IEA, 2023).

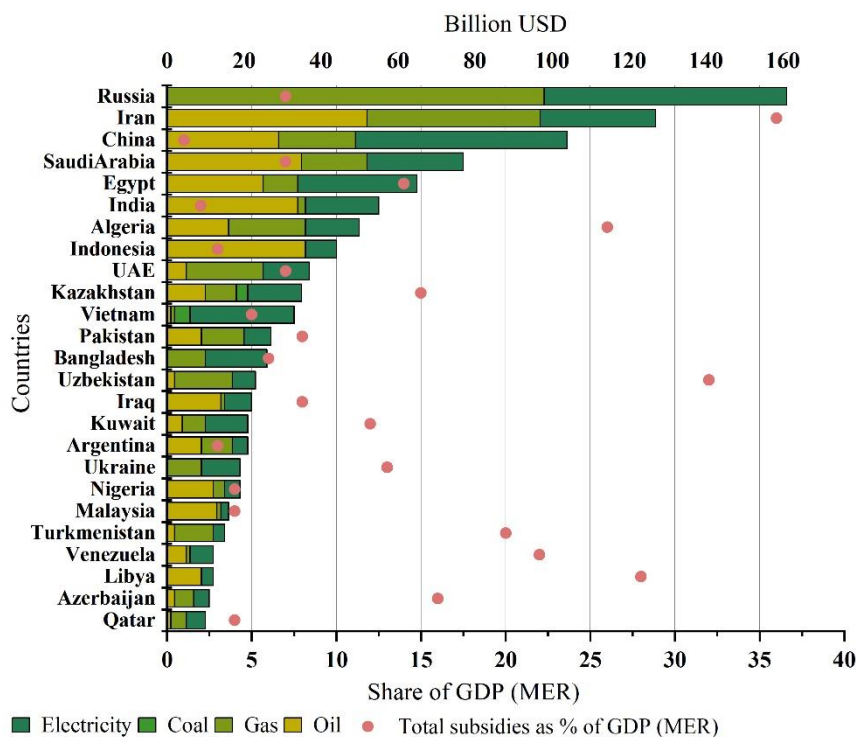
According to the International Energy Agency (2023), Iran ranks among the world's largest providers of energy subsidies. Over the past decade, these subsidies have ranged from \$30 billion to \$137 billion, with significant fluctuations primarily influenced by changes in global fossil fuel prices. The IEA's estimation is derived from a price-gap approach. In 2020, subsidies allocated to electricity, natural gas, and oil products were \$12.5 billion, \$12.2 billion, and \$5.0 billion, respectively (International Energy Agency, 2023). This indicates that the electricity sector has become the largest recipient of energy subsidies in Iran. Notably, the country possesses considerable potential for renewable energy, particularly in solar and wind power (Ghorbani et al., 2020).

The extensive fossil fuel subsidy programs have distorted market equilibrium in Iran, rendering energy efficiency initiatives and renewable energy technologies uncompetitive. As a result, fossil fuel-based technologies continue to dominate the electricity generation mix. In 2017, this sector was responsible for emitting over 170 million tons of carbon dioxide (Aryanpur, Ghahremani, et al., 2022).

Aryanpur, Fattahi, et al (2022) found that reforming energy subsidies could cut overall electricity demand by 16% and reduce total CO<sub>2</sub> emissions by 31%. The analysis suggests that if reforms are implemented early and gradually, renewable energy technologies and energy efficiency measures become more cost-effective. On the other hand, a sudden and late removal of subsidies might risk locking in existing practices. This highlights the importance of prioritizing early action on energy subsidy reforms rather than focusing solely on how quickly subsidies are removed. Lastly, the paper also explores the potential policy implications of these findings beyond Iran. Moshiri (2015) evaluated the effectiveness of Iran's 2010 energy price reform, which involved removing energy subsidies and providing cash handouts to households. Using a two-stage consumer optimization model and data from the household budget survey (2001–2008), the study estimates energy demand elasticities for different income groups. The findings show that overall price elasticities are low, but income elasticities are close to one. Urban households are more responsive to price changes, while rural households, especially middle-income groups, are more sensitive to income changes. These results suggest that price increases alone are insufficient to reduce energy consumption, and that policies should also focus on improving energy efficiency through a combination of price and non-price measures.

Barkhordar (2019) proposed an LED Replacement Lamps Program in Iran to reduce household electricity demand through the distribution of free energy-efficient LED lamps. Given the country's heavily subsidized electricity, the program's primary benefit for the government would be avoiding subsidy payments. A cost-benefit analysis suggests the program could be profitable if the expected electricity savings are realized. However, a potential rebound effect where increased energy

efficiency leads to higher overall energy demand could reduce the savings. Using a hybrid dynamic general equilibrium model, the study found an average economy-wide rebound of 43.8%, but the program remains profitable despite this effect. Araghi and Barkhordari (2012) analyzed the impact of energy price reforms in Iran, where subsidized energy has led to high per capita consumption. It finds that raising energy prices reduces household energy use. Welfare impacts depend on government compensation: a 100% or 200% price increase improves household welfare if 20–50% of the revenue from subsidy removal is redistributed. However, welfare declines with a 400% or 500% price hike if only 20–30% is redistributed. This highlights the need for balanced reforms and compensatory policies to mitigate adverse effects.



**Figure 7.** Value of fossil-fuel subsidies by fuel in the top 25 countries, 2022. Created by author based on (IEA, 2023).

## **2.7. Methodologies for assessing CO<sub>2</sub> emissions and inequality**

### **2.7.1. Most recent methods and findings in the research of CO<sub>2</sub> emissions and inequality**

Many studies have employed different methodologies to investigate and assess CO<sub>2</sub> emissions. In general, most studies have used inequality measures such as the Theil index and the Gini coefficient, as well as econometric models. Padilla and Serrano (2006) using methods typically employed in income distribution analysis. They provide both qualitative and quantitative insights into key aspects of international inequalities relevant to climate policy design. It finds that income inequality among countries has led to significant disparities in CO<sub>2</sub> emissions distribution.

Padilla and Duro (2013) investigated the formulation of European mitigation policies necessitates a thorough analysis of the factors contributing to unequal emissions across different countries. This research examines the changes in CO<sub>2</sub> emissions per capita inequality within the EU-27 from 1990 to 2009 and identifies the factors driving these changes. By decomposing the Theil index of inequality, the study assesses the impact of various Kaya factors and explores inequalities between and within country groups (Northern, Southern, and Eastern Europe).

The "Global Covenant of Mayors Common Reporting Framework Version 7." establishes a structured approach for local governments to report their climate actions and commitments under the Global Covenant of Mayors for Climate and Energy (gCoM). It provides two reporting levels comprehensive and simplified to accommodate cities of varying capacities. Key components include greenhouse gas emissions inventories, emissions reduction targets, risk assessments, and energy access measures. The framework encourages transparency and accountability in climate action, facilitating data aggregation and comparison across regions. By prioritizing ambitious targets and clear action plans, it aims to enhance local government contributions to global climate goals. Overall, this framework serves as a vital tool for cities to navigate their climate commitments effectively (Global Covenant of Mayors Common Reporting Framework, 2023). The CO<sub>2</sub> emissions assessment methodology outlined in the Sustainable Energy Action Plan (SEAP) and Sustainable Energy and Climate Action Plan (SECAP) provides a systematic approach for local governments to evaluate and manage their greenhouse gas emissions. This methodology emphasizes the importance of comprehensive data collection, including activity data and emission factors, to ensure an accurate inventory of CO<sub>2</sub> emissions across various sectors, such as energy, transportation, and waste. Local authorities are guided to establish clear baselines and targets to

monitor progress over time, facilitating strategic decision-making for climate mitigation. By integrating this assessment into broader climate action strategies, local governments can effectively identify reduction opportunities, enhance accountability, and contribute to sustainable energy transitions while aligning with regional and global climate objectives (Global Covenant of Mayors Common Reporting Framework, 2023).

The study by Billio et al (2024) focused on predicting energy efficiency improvements in residential buildings using advanced machine learning models, specifically comparing tree-based models like XGBOOST with traditional linear models. Xiao et al (2024) studied A province-level bottom-up model evaluates energy consumption and regional disparities under various carbon neutrality pathways.

This study by Huang and Tian (2021) analyzed CO<sub>2</sub> emissions inequality among various income groups in eight developing countries using an input-output model. It also examines the effects of the COVID-19 outbreak on emissions inequality using a hypothetical extraction method, finding that the outbreak has reduced both CO<sub>2</sub> emissions inequality and overall emissions over time. However, simulations based on shared socioeconomic pathways indicate that long-term CO<sub>2</sub> emissions inequality will persist. Guo et al (2023) examined the uncertainty significantly impacts the projection of energy consumption and CO<sub>2</sub> emissions from buildings, affecting mitigation and adaptation strategies. Due to multiple uncertainties, predicting the future energy consumption and CO<sub>2</sub> emissions of China's buildings is challenging. To provide a clearer picture of these uncertainties, a bottom-up national energy technology model for the building sector (NET-Building) has been developed. Dou et al (2021) examined the evolutionary paths of energy consumption and CO<sub>2</sub> emissions, considering the uncertain future trends of key influencing variables. This study examines the impact of energy inequality on household CO<sub>2</sub> emissions in China, using a balanced panel dataset from 30 provinces between 2000 and 2017. Acknowledging potential cross-sectional dependence, the study employs various empirical approaches that account for this factor.

Mitić et al (2023) examined the causal relationships between CO<sub>2</sub> emissions, economic growth, available energy, and employment in eight South-Eastern European countries from 1995 to 2019. Using panel unit root tests, panel cointegration methods, and panel causality tests, they investigate these relationships. Miao et al (2019), In the study, China was divided into three regions so that regional variances could be considered. The main factors influencing household CO<sub>2</sub> emissions are examined using an extended stochastic impact by regression on wealth, population, and technology (STIRPAT) model.

Oberheitmann (2012) investigated domestic sector CO<sub>2</sub> emissions of China with applying econometrics models. Hajilary et al (2018) used a factorial design to examine the impact of Iran's socioeconomic situation on CO<sub>2</sub> emissions. The goal is to determine the significant factors and how they relate to carbon emissions. Altouma et al (2024) the Autoregressive Distributed Lag (ARDL) model was employed to examine the long-term interaction and short-term dynamic forces among the variables studied over the period from 1970 to 2020. According to the model, CO<sub>2</sub> emissions from petroleum-related production, GDP, industry, services, and agriculture all have short-term effects on the environment. In particular, the industrial sector contributes to lowering CO<sub>2</sub> emissions whereas the GDP, the agricultural sector, services, and oil production all contribute to increased emissions. The model also indicates that a 1% increase in GDP leads to a 3.46% rise in CO<sub>2</sub> emissions, while a 1% increase in oil production results in a 4.04% rise. Conversely, a 1% increase in industrial activity reduces CO<sub>2</sub> emissions by 7.25%.

Hussain et al (2022) findings indicated that the Autoregressive Integrated Moving Average (ARIMA) model is the most suitable for anticipating gas consumption in Pakistan. Up until 2030, the household sector's growth in compacted natural gas consumption is predicted to surpass that of all other economic sectors. The main conclusions indicate that (a) Utilizing natural gas is probably going to continue growing over time, (b) there are varying forecast trends for the total amount of natural gas used and consumption trends across different sectors, and (c) It is anticipated that Pakistan's natural gas production and demand gap will lead by 2030.

Somosi et al (2024) utilized a panel autoregressive (VAR) model to study A set of expanding Southeast Asian nations, where economic and population expansion are anticipated to drive up CO<sub>2</sub> emissions in the future. We also explore the challenges these countries face in meeting CO<sub>2</sub> emission targets and incorporate modern renewable energy sources (RES) into our quantitative analysis. The results reveal that rebound effects and increasing costs associated with modern RES have hindered these countries long-term efforts to reduce CO<sub>2</sub> emissions. Mohammed et al (2024) outlined a thorough line to evaluating the effects of CO<sub>2</sub> emissions, energy consumption, population structure, economic growth, and policy measures on the environment within the EU, using the Environmental Kuznets Curve (EKC) as a framework. The EU GDP and CO<sub>2</sub> emissions have an overturned U-shaped association, according to the experimental EKC research.

Park and Yun (2022) examined the factors influencing electricity consumption across 225 South Korean municipalities from 2010 to 2019, employing a spatial panel model to account for local attributes and changes over time in social factors. The findings indicate that residential electricity consumption in metropolitan areas and

neighboring regions exhibited similar spatial patterns. Social factors such as household size, marriage rates, and apartment living significantly influenced electricity usage, with the interaction effects highlighting the specific impacts of ageing populations and apartment living in greater detail.

### 2.7.2. Bibliometric analysis of CO<sub>2</sub> emissions and energy research

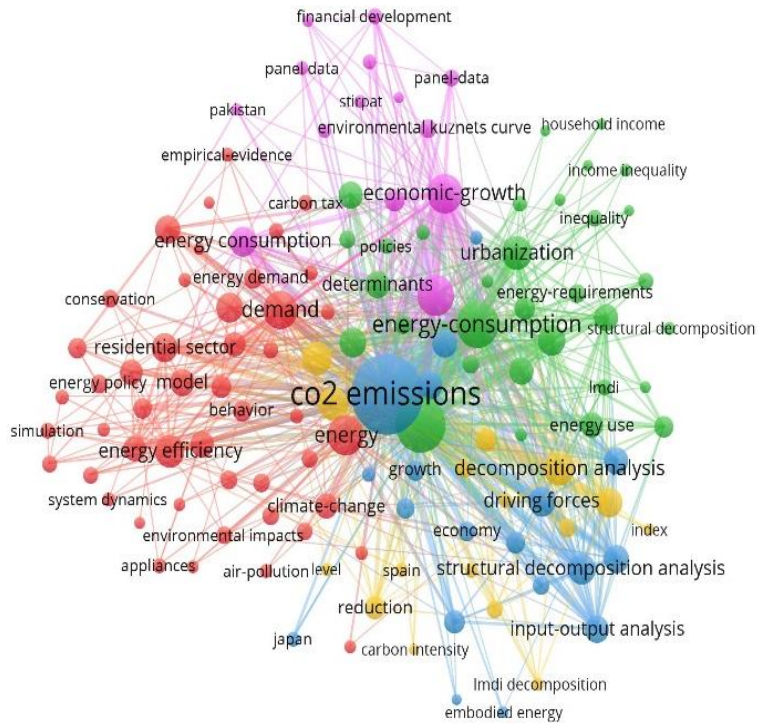
Bibliometric analysis offers insight into research trends, influential topics, and methodologies in the field of CO<sub>2</sub> emissions and energy consumption. By analyzing a set of relevant literature, this section identifies the most frequently studied regions, popular research methodologies, and the dominant themes surrounding CO<sub>2</sub> emissions and energy inequality. Using the keywords ‘energy,’ ‘consumption,’ ‘CO<sub>2</sub>,’ ‘emissions,’ ‘household,’ and ‘sector,’ a bibliometric search was conducted in the Web of Science (WOS) database, resulting in 533 relevant documents. VOSviewer software was employed to perform a co-occurrence and clustering analysis, revealing five primary research clusters Figure 8. Table 2 provides a summary of various important econometric methodologies used in the investigation of energy consumption and CO<sub>2</sub> emissions.

**Table 2.** Summary of different methods for assessing CO<sub>2</sub> emissions and energy

Model	Study Area	input	output	reference
ARDL	Saudi Arabia	GDP, agriculture, industry, services, and oil production	GDP, agriculture, services, and oil production contribute to higher CO <sub>2</sub> emissions	(Altouma et al., 2024)
ARIMA	Pakistan	household, industrial, commercial, transport, fertilizer production, power generation, and cement production	Natural gas consumption in Pakistan is projected to grow, with varying trends across sectors, and a widening gap between consumption and production expected by 2030.	(Hussain et al., 2022)
VAR	Southeast Asia	economic growth and increased energy consumption	rebound effects and increasing costs associated with modern RES have hindered these countries' long-term efforts to reduce CO <sub>2</sub> emissions	(Somosi et al., 2024)
EKC	EU-27	energy consumption (EC), population structure (POP), economic growth (GDP), and policy	The empirical EKC analysis reveals an inverted U-shaped relationship between	(Mohammed et al., 2024)

			GDP and CO <sub>2</sub> emissions in the EU-27	
SAR	South Korea	local characteristics ,household size, marriage rates, and apartment living	household size, marriage rates, and apartment living significantly influenced electricity usage, with the interaction effects highlighting the specific impacts of ageing populations and apartment living in greater detail	(Park & Yun, 2022)

Figure 8 represents a bibliometric analysis that illustrates previous research conducted within clusters to identify the most important topics, as well as the different methods and relationships between these topics. According to Figure 8, five key research clusters are identified as most important in terms of CO<sub>2</sub> emissions and energy consumption within the building sector. The first cluster, shown in blue, focuses on CO<sub>2</sub> emissions, decomposition analysis, carbon intensity, and economic factors. The second cluster, in red, highlights research on energy consumption, energy efficiency, the residential sector, and climate change. The third cluster, represented in green, emphasizes the importance of inequality in energy consumption, examining factors such as urbanization and household income. The fourth cluster, in purple, addresses economic growth and the use of panel data, while the fifth cluster, in yellow, illustrates studies on policy and strategies for mitigating CO<sub>2</sub> emissions. According to the literature in web of science the majority of research on CO<sub>2</sub> emissions has been conducted in China. Various methodologies have been employed to identify the driving factors and inequality in CO<sub>2</sub> emissions across regional and residential sectors.



**Figure 8.** The bibliometric analysis of the search related to the research topic, using the equation (energy AND consumption AND CO<sub>2</sub> AND Emissions AND Household AND Sector) in WOS (n=533 documents). VOSviewer analysis identified 5 clusters. (Created by author)

## 2.8. Key aspects of the global and Iranian energy economy and CO<sub>2</sub> emissions

The pressing global need to decarbonize is exemplified by the swift expansion in research and implementation of new low-carbon infrastructure across the energy sector. This shift is driven by national initiatives such as the United States' pledge to establish a carbon-free power sector by 2035 and achieve a net-zero emissions economy by 2050, the European Union's legislation to reduce emissions by 55% by 2030 and reach net-zero by 2050, and China's target to attain net-zero emissions by 2060 (IEA, 2021). In Figure 9, CO<sub>2</sub> emissions from different sectors on a global scale are shown to be increasing in many sectors. Meanwhile, in some sectors, emissions remain constant or are slightly increasing. The building sector, after 1990, exhibits a

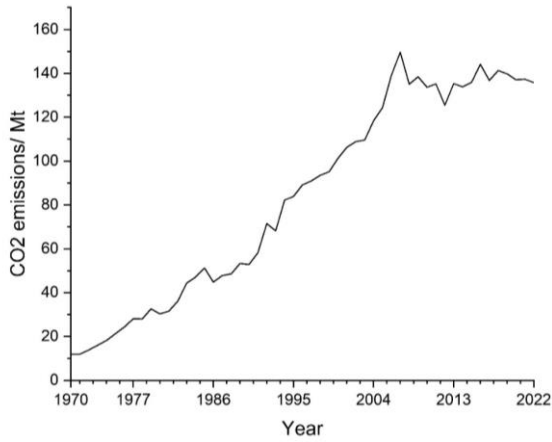
reduction in CO<sub>2</sub> emissions. The power industry has shown significant growth from 1970 to 2022; however, the transport sector and industrial combustion have also experienced a dramatic increase over this period.

Figure 10 illustrates CO<sub>2</sub> emissions in the building sector in Iran, which shows an increasing trend from 1970. Between 1970 and 2022, Iran experienced substantial changes in CO<sub>2</sub> emissions from the household sector, driven by several key factors that led to a significant increase in emissions.

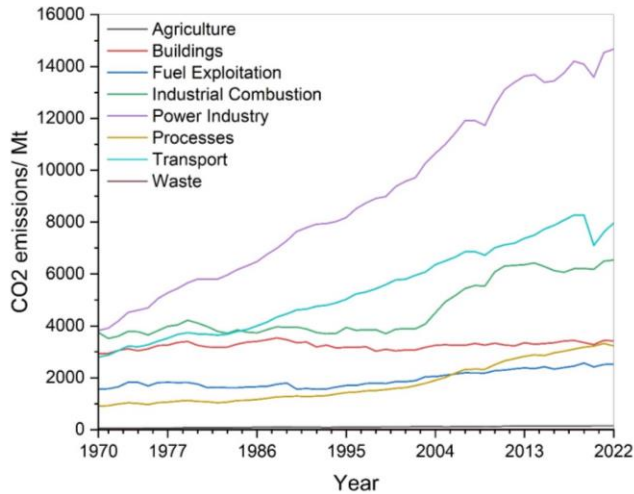
Firstly, rapid urbanization and population growth played a central role. Iran's population grew dramatically over these decades, especially in urban areas. This urban expansion spurred a rise in residential buildings and infrastructure, creating a greater demand for energy to power homes, appliances, and comfort systems like heating and cooling.

Secondly, the overall energy demand surged, partly due to a rising standard of living and the growing need for electricity and heating in households. Iran's households became more dependent on energy-intensive appliances and systems. Iran has traditionally relied on fossil fuels heavily due to its abundant oil and gas resources. The extensive use of fossil fuels for electricity generation, heating, and cooking further compounded emissions.

The third significant change occurred after 2000, with a major shift to natural gas as the primary energy source for households. In response to rising energy needs and to reduce dependency on other fuels like kerosene and oil, Iran promoted natural gas as a cleaner alternative. This transition did help to slightly mitigate emissions compared to using other, more carbon-intensive fossil fuels. However, as natural gas use became widespread, the household sector's overall emissions continued to grow, especially as demand increased with population and urban expansion. Lotfalipour et al (2010) examined the causal relationships between economic growth, carbon emissions, and fossil fuel consumption in Iran from 1967 to 2007, using the Toda-Yamamoto method. The analysis finds a unidirectional Granger causality from GDP and energy consumption (petroleum products and natural gas) to carbon emissions, but no causality from total fossil fuel consumption to emissions in the long run. Additionally, while gas consumption influences economic growth, neither carbon emissions nor petroleum and fossil fuel consumption have a causal effect on economic growth. These results highlight the complex interactions between energy consumption, emissions, and economic performance.



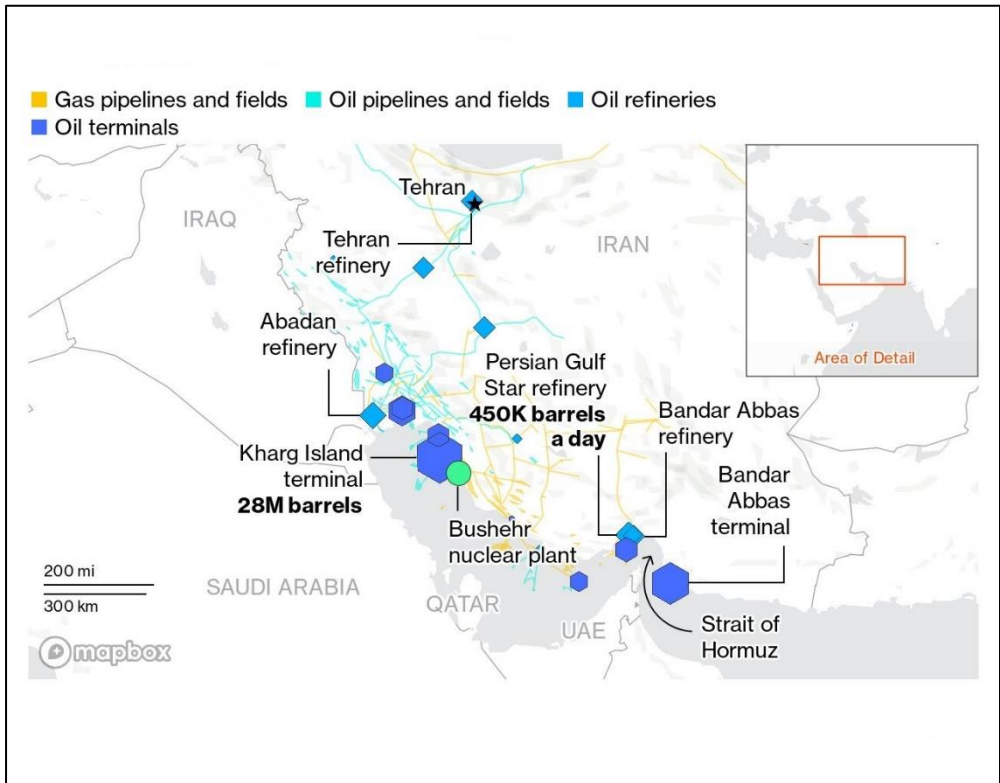
**Figure 9.** CO<sub>2</sub> emissions from different sectors in global scale from 1970 to 2022 (European Commission, 2023), created by author by the dataset from European Commission, 2023.



**Figure 10.** CO<sub>2</sub> emissions from building sector in Iran from 1970 to 2022 , created by author by the dataset from European Commission, 2023.

Figure 11, shows the distribution of Iran’s oil and gas assets. Most resources are located in the south of Iran, particularly in the Persian Gulf and Khuzestan Province,

with one or two refineries situated in the capital, Tehran. Oil and gas pipelines extend from the south, reaching nearly all provinces in Iran. However, there is a notable lack of pipeline infrastructure in the eastern provinces, such as Sistan and Baluchestan and South Khorasan. Despite their proximity to resources, these provinces lack direct access to pipelines, resulting in unequal distribution of gas and oil across Iran. Kharg Island Terminal, with a capacity of 28 million barrels, is the most significant oil terminal in Iran. Another key facility is the Persian Gulf Star Refinery in the south, with a capacity of 450,000 barrels per day.



**Figure 11.** The map of Iran oil and gas assets. (Bloomberg, 2024).

## 2.9. Energy production, consumption, pricing and markets

The urgent need to reduce carbon emissions is highlighted by the swift expansion of research and the implementation of new low-carbon infrastructure across the energy sector (Haugen et al., 2024). Along with the environment, reduced energy use has a significant impact on financial risk management. First, greenhouse gas emissions are one of the main factors contributing to transition risk (Basel Committee on Banking

Supervision, 2021). Second, new research on the mortgage credit market suggests that energy-efficient buildings have a lower solvency risk (Billio et al., 2021; Ferentinos et al., 2023; Guin et al., 2022).

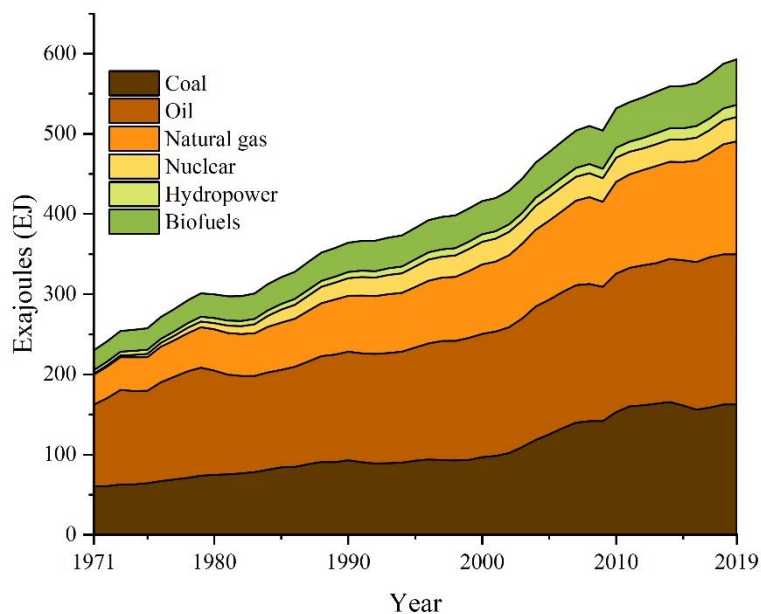
Energy issues have significant impacts on economic development, social stability, and national security, making them critical topics that must be addressed. This is supported by data from the BP Statistical Review (BP Statistical Review of World Energy, 2022). To reach carbon neutrality, it is essential to move away from the economic model that depends on fossil fuels, leverage new technologies, and harness renewable energy to discover new routes for energy transition. Renewable energy, with its clean and sustainable nature, is regarded as one of the most promising and effective solutions for combating global warming (Smil, 2020).

Digital platforms have been utilized by oil and gas businesses to improve decision-making about exploration and production. The efficiency of transportation has been greatly increased by technologies like GPS route optimization, vehicle networking, and autonomous driving. Digital platforms for management and monitoring have also made it easier for solar and wind energy to be integrated into the grid and used widely. In order to assist the development of renewable energy, grid companies can now forecast and optimize the absorption and dispatch of renewable energy, provide energy risk alerts, and carry out valley filling. On the other hand, as the digital economy has expanded, so has the demand for data and digital services. This entails building a large number of data centers and network infrastructures, managing operations and maintenance, and recycling electronic devices, all of which increase energy demand. In light of the "double carbon" goals, providing green energy for the digital economy has become essential. China's "Eastern Data Western Calculation" project aims to integrate the data center industry with renewable energy, efficiently balancing industrial supply and energy consumption. This synergy means that the digital economy bolsters renewable energy, while renewable energy sustains the digital economy. Through the comprehensive utilization of renewable energy and the digital economy, along with the promotion of their deep integration, nations can establish a system impact that will expedite global energy conservation and carbon reduction (Jiao et al., 2024).

To examine global energy supply, Figure 12 illustrate the growth of different energy sources from 1971 to 2019 (Energy Agency, 2021). According to Figure 12, coal, oil, and natural gas, all of which are fossil fuels, dominate the majority of energy supply and are responsible for the majority of CO<sub>2</sub> emissions worldwide.

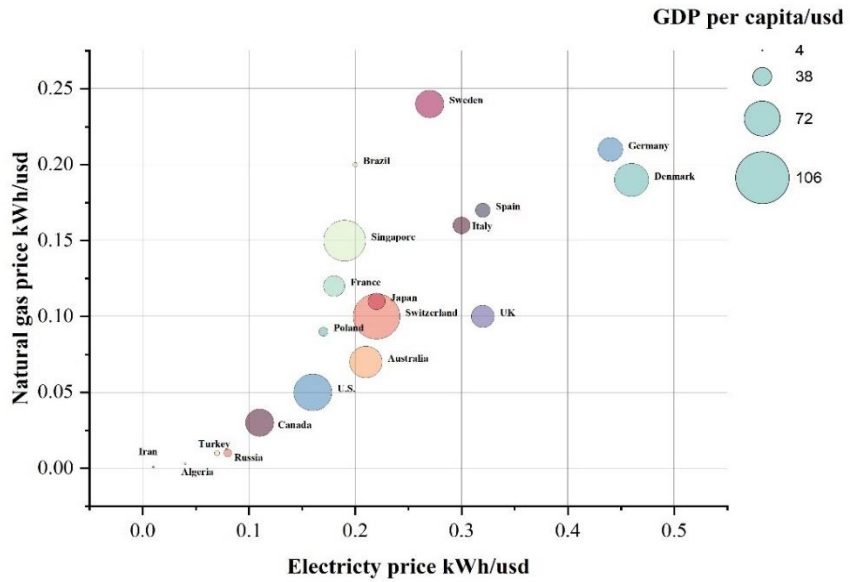
Important and newly related topics include supply chain pressures, CO<sub>2</sub> emissions, the circular economy, and the energy transition. The circular economy is

becoming a well-known response to climate change as demands grow and there are more and more requests for a significant change in global energy regulations to cut emissions (Gallego-Schmid et al., 2020).

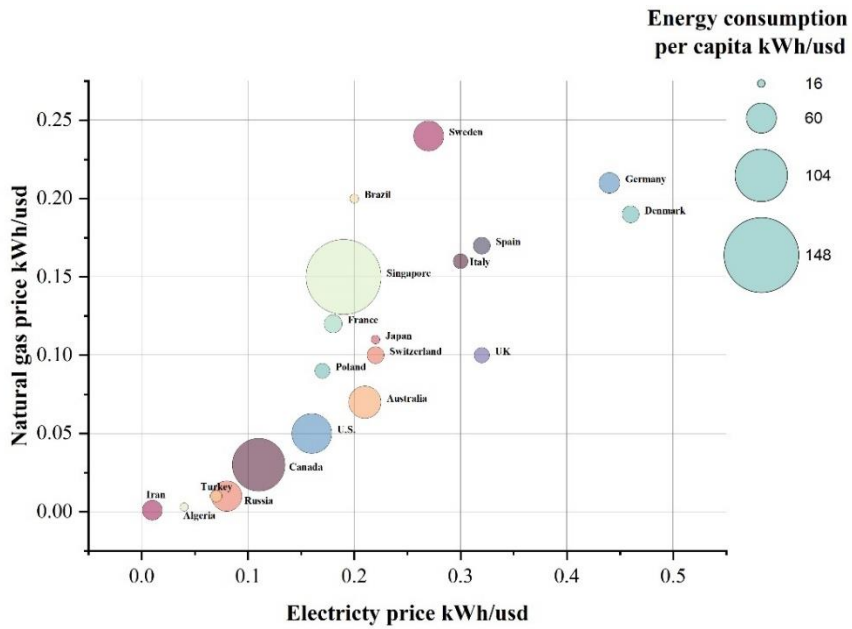


**Figure 12.** Energy supply by different sources from 1970 to 2019 created by Author based on (energy Agency, 2021).

According to Figure 13, countries such as Sweden, Germany, and Denmark, which have high GDP per capita, also experienced extremely high gas and electricity prices in 2022. In contrast, countries like Iran, Algeria, Türkiye, and Russia, with lower GDP per capita, had some of the lowest gas and electricity prices in 2022. Notably, Iran had the lowest prices for both gas and electricity. Figure 14 shows the relationship between electricity and gas prices and energy use per capita. Canada, the US, Australia, and Singapore have the highest energy consumption per capita, with their energy prices falling in the middle range. Interestingly, despite having the lowest energy prices (for gas and electricity), Iran and Russia have high per capita energy consumption, indicating lower efficiency in using cheap energy sources.



**Figure 13.** Price of electricity and natural gas in terms of GDP per capita between selected countries. Created by the author based on data from Global Petrol Prices (2022).



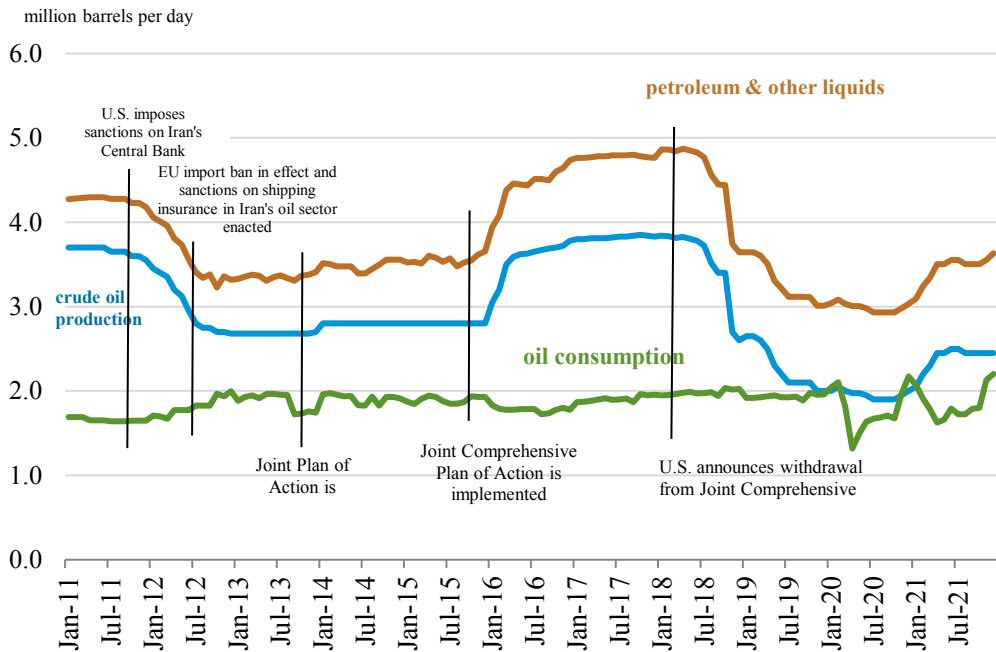
**Figure 14.** Price of electricity and natural gas in terms of energy consumption among selected countries in 2022. created by the author based on data from Global Petrol Prices (2022).

## **2.10. Iran's situation in terms of energy market**

A comparison of Iran's energy situation in 2021 with similar figures from 2013 shows that the total primary energy supply grew at an annual rate of 1.3%, increasing from 1,662.9 million barrels of oil equivalent in 2013 to 2,119.4 million barrels of oil equivalent in 2021. Meanwhile, total final energy consumption grew at an annual rate of 1.3%, rising from 1,237.6 million barrels of oil equivalent to 1,583.9 million barrels of oil equivalent. This increase in final energy consumption highlights the growing need for continued and accelerated efforts to optimize both energy supply and demand (Ministry of Energy, 2021). In 2021, the real price of electricity increased by 19% to 417 rials (0.17 cents) per kilowatt-hour. The real price of oil also rose by 22.8% to 7,656 rials (3.2 cents) per liter. However, the real price of natural gas decreased by 14.6% compared to 2020, reaching 197.7 rials (0.08 cents) per cubic meter in 2021 (Ministry of Energy, 2021).

In 2021, Iran ranked as the fifth-largest producer of crude oil within OPEC, and in 2020, it was the third-largest producer of natural gas globally (U.S. Energy Information Administration, 2022b). In 2020, Iran's crude oil production fell to its lowest level in three decades due to the effects of sanctions and the economic repercussions of the COVID-19 pandemic. However, production saw a modest increase in 2021 as global demand for oil grew (Reuters, 2022).

In 2017, prior to the re-imposition of sanctions by the United States, Iran's exports of crude oil and condensate averaged over 2.5 million barrels per day in Figure 15. By 2020, this figure had dropped to an average of 0.4 million barrels per day. Starting in November 2020, Iran's oil exports began to increase, reaching an average of over 0.6 million barrels per day in 2021, largely due to increased shipments to China. According to estimates from ClipperData, Iran's oil exports averaged more than 0.7 million barrels per day in the first quarter of 2022. However, in the second quarter of 2022, exports fell to under 0.6 million barrels per day due to high prices that dampened demand in China and increased competition from Russian oil shipments (ClipperData, 2022).

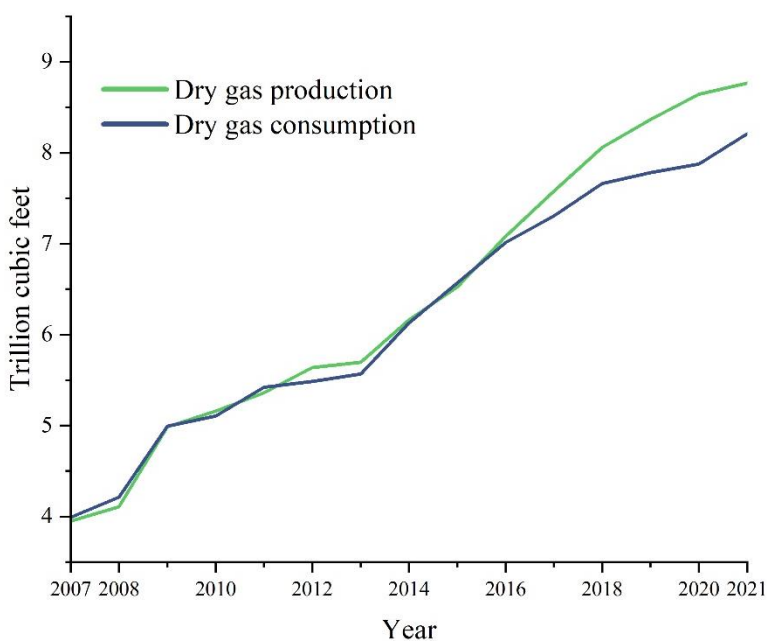


**Figure 15.** Iran's petroleum and other liquids production and consumption, (U.S. Energy Information Administration, 2022a).

As of December 2021, Iran’s proved natural gas reserves were estimated at 1,200 trillion cubic feet (Tcf), making it the second largest globally after Russia, according to the Oil & Gas Journal. Iran possesses 17% of the world's confirmed natural gas reserves and nearly 50% of those held by OPEC (Oil & Gas Journal, 2021). Since 2018, domestic companies have mainly developed Iran's natural gas fields. However, growth in natural gas production, especially from fields that yield condensate liquids, is constrained by limited storage capacity for condensate. This situation persists due to ongoing sanctions on Iran's oil exports. Iran will need to invest over \$20 billion to construct compression stations to prevent pressure drops and production decreases in some of the older phases of the South Pars field. Without adequate investment in these fields, Iran estimates a potential loss of around 350 billion cubic feet (Bcf) per year in natural gas production beginning in 2023 (Middle East Economic Survey, 2022b). Iranian domestic companies are working on developing additional natural gas fields; however, it is anticipated that progress will be quite slow as long as the sanctions continue (Facts Global Energy, 2021). Without investment from international companies, Iran will struggle to fulfil its natural gas demand through domestic production alone.

Iran was the world's fourth-largest natural gas consumer in 2021, following the United States, Russia, and China. The majority of Iran's natural gas production is used within the country (BP, 2022). Upon the past ten years, domestic natural gas consumption has soared by roughly 50% due to several factors:

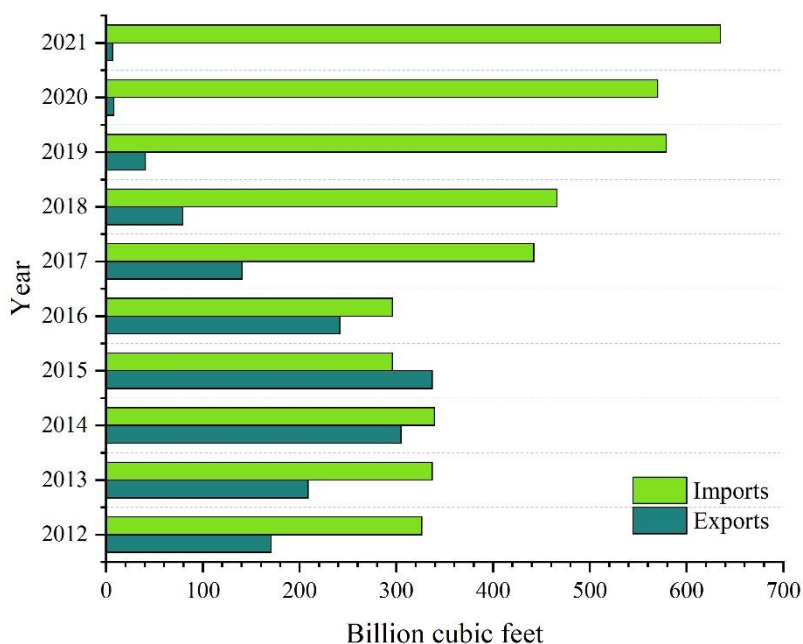
- Substantial subsidies on prices
- A comprehensive grid infrastructure
- Growth in domestic production
- Government efforts to shift oil to natural gas in residential, commercial, and electricity generation sectors.



**Figure 16.** Natural gas production and consumption in Iran, 2007-2021. Created by the author based on the data from U.S. Energy Information Administration (2022a).

In 2020, the highest share of natural gas consumption was in the residential and commercial sectors (35%), with the industrial sector (including petrochemicals) following at 27%, and the electric power sector at 26%. Over the past ten years, consumption across all these sectors has risen considerably due to the replacement of some liquid fuels with natural gas as shown in Fig 16, the expansion of Iran's natural gas pipeline network, and growth in the industrial sector (Facts Global Energy, 2021).

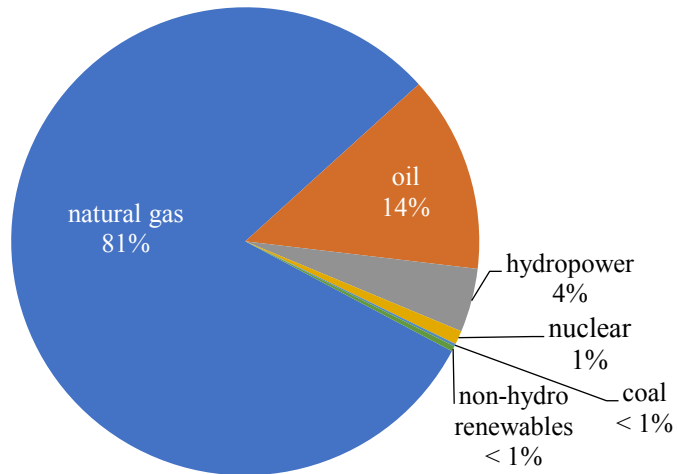
Iran exports natural gas through pipelines to Türkiye, Armenia, Azerbaijan, and Iraq as shown in Fig 17, and it imports gas from Azerbaijan and Turkmenistan. In 2021, Iran's natural gas exports via pipelines totaled approximately 635 billion cubic feet, while its imports amounted to 7 Bcf. Since 2015, Iran has significantly reduced its natural gas imports, while its exports have surged since 2014. This increase in exports is attributed to greater natural gas production from various new South Pars projects and a rise in exports to Iraq starting in 2017 (U.S. Energy Information Administration, 2022a).



**Figure 17.** Iran's natural gas pipeline imports and exports. Created by the author based on the dataset of U.S. Energy Information Administration (2022a).

Iran generated 341 terawatt-hours (TWh) of net electricity in 2021, with 94% of this generation coming from fossil fuel sources (U.S. Energy Information Administration, 2022a). In Iran, natural gas is the predominant fuel for electricity generation, contributing nearly 81% of the total output. Oil accounted for 14% of the country's electric power generation in 2021, an increase from 9% in 2018 shown in Figure 18 (BP, 2022; U.S. Energy Information Administration, 2022a). In recent years, factors such as illicit cryptocurrency mining, a rising population, heavily

subsidized electricity rates, and fuel supply shortages have contributed to an increasing demand for electricity in Iran. This surge in demand has put a strain on the country's capacity, especially during peak seasons in summer and winter. Consequently, these conditions resulted in power shortages in both 2020 and 2021(BBC, 2021). During the summer of 2021, Iran's electricity demand during peak periods surpassed its supply by almost 12 gigawatts (GW) (Middle East Economic Survey, 2022a).



**Figure 18.** Iran's electricity generation capacity by fuel, 2021 (EIA, 2022)

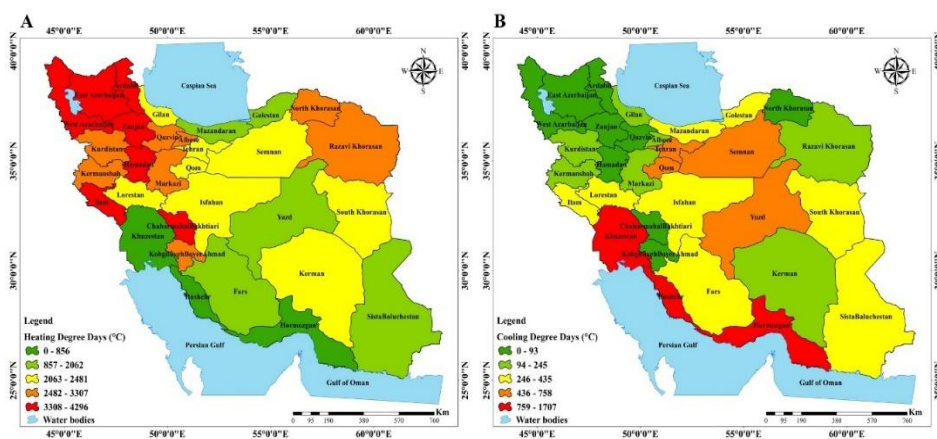
## 3. Methods and Materials

### 3.1. Study area

Iran is a country with 1.648 million km<sup>2</sup> and locates among 45° and 63° East and 25°–40° North in the Middle East. The climate of Iran is very diverse, in general Iran has arid and semi-arid climate (Fallah et al., 2017; Sodoudi et al., 2010). Most of the country experiences rainy season from November to May, followed by a dry season with sporadic precipitation from May to October. The country receives approximately 240 mm of rainfall on average per year, with the highest amounts occurring in the Alborz and Zagros slopes at over 1,600 and 480 mm, respectively. Depending on the region, precipitation levels at the central and eastern plains drop to less than 100 mm yearly. According to synoptic factors, subtropical highs dominate Iran's climate for the most part of the year. The summertime climate is made hot and dry by this phenomenon. Mediterranean synoptic systems, which migrate eastward with westerly winds throughout the cold season, are responsible for the nation's rainfall (Fallah et al., 2017). The three nations that account for more than 65% of the region's fossil fuel-related CO<sub>2</sub> emissions are Iran (168.25 million tons), Saudi Arabia (147.65 million tons), and Türkiye (88.21 million tons). Iran ranks seventh in the world for total CO<sub>2</sub> emissions, which come to approximately 168,251 thousand metric tons of carbon (616,741 million tons of CO<sub>2</sub>) (Mansouri Daneshvar et al., 2019). Iran's historical and geographical position has always made it susceptible to the consequences of climate change. Situated in the desert belt, Iran has only one-fourth of the water resources in terms of rainfall and surface water. This highlights the critical need to focus on various aspects of climate change (Kaviani Rad, 2017).

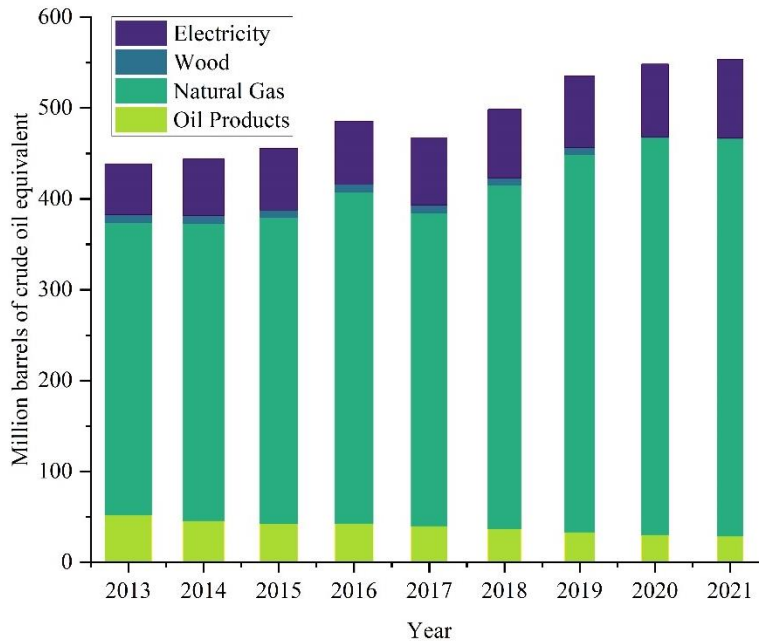
Figure 19 illustrates that in the southern region of Iran, there are more Cooling Degree Days (CDD) than Heating Degree Days (HDD). Per reports, the average HDD and CDD are 856°C and 1707°C in Khuzestan, 228°C and 1594°C in Hormozgan, and 1757°C and 435°C in Sistan and Baluchestan, respectively. Yazd and Isfahan, the two largest provinces in Iran, have hot, dry summers and cold, dry winters. Figure 17 shows that the amount of CDD in Yazd and Isfahan is approximately at or slightly above the average. In contrast, the HDD values are average for Isfahan and below average for Yazd. There are two groups of northern provinces: those that are close to the Caspian Sea and those that are far from Caspian Sea. Gilan is a northern province on the southwest coast, and Golestan lies southeast of the Caspian Sea. The HDD at the Gilan meteorological station, which is representative of the southwest Caspian Sea regions, is 2232°C based on long-term yearly averages. Moving eastward, this HDD drops to 2062°C in Golestan. Northern provinces generally have average HDD values, indicating a higher need for heating than cooling throughout the year. Ardebil is known for its extreme cold and is located in the Northwestern part of the country with cool summers and extremely frigid winters. According to the map, Ardebil has

the greatest HDD of any province, with an average yearly temperature of 14.9°C and a relative humidity of 71.55%. As seen by its high HDD values on the map, the Khorasan station in northeastern Iran has severe effects from Siberian high pressure throughout the winter period, leading to cold and dry conditions. East Azerbaijan and Kermanshah, which similarly exhibit high HDD values on the map, reflect the western and northwestern Iranian stations, which are influenced by the Mediterranean and Red Sea systems and their rainfall.



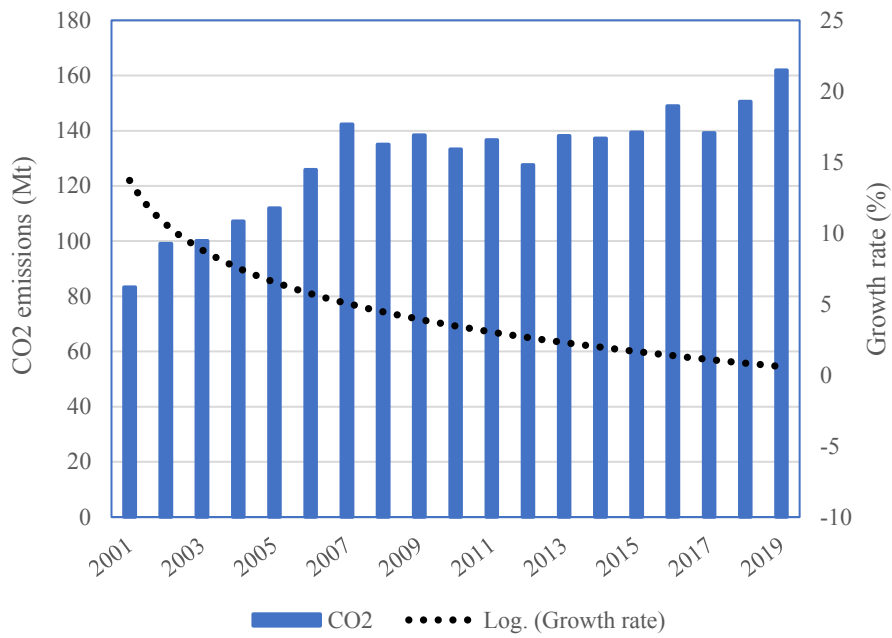
**Figure 19.** A. Average of HDD, B. Average of CDD, in the provinces of Iran from 1977 to 2019. (Created by the author)

According to Figure 20, most of the energy consumption in the household sector is due to natural gas, followed by electricity. However, the consumption of oil products in the household sector has dramatically reduced in recent years. Meanwhile, natural gas consumption has increased, driven by the expansion of pipeline infrastructure across the country. Electricity consumption also shows an increasing trend from 2013 to 2021 in the household sector in Iran. An examination of the average annual energy expenditure of urban and rural households in Iran, broken down by different cost deciles in the year 2021, shows that energy costs accounted for about 3% of the total expenses of urban households and 4.4 of the total expenses of rural households (Ministry of Energy, 2021). Iran has some of the lowest electricity prices in the world since it offers a sizable amount of subsidies. Iran's domestic electricity demand has increased as a result throughout time (Fattouh & El-Katiri, 2013). Natural gas is the most heavily subsidized resource in Iran, resulting in low electricity prices. Consequently, this has contributed to a rising trend in CO<sub>2</sub> emissions from natural gas compared to other primary energy sources (Fatourehchi et al., 2022).



**Figure 20.** Different kind of fuels used in household sector from 2013 to 2021. Created by the author based on the datasets from Ministry of Energy (2021).

Figure 21 illustrates the CO<sub>2</sub> emissions in Iran from 2001 to 2019. CO<sub>2</sub> emissions in the residential sector rose from 82 million tons in 2001 to 162 million tons in 2019. However, the growing value declined over this period. Notably, the trend of CO<sub>2</sub> emissions showed a decrease after 2007, and from 2007 to 2013, there was no significant increase in CO<sub>2</sub> emissions. Iran, ranking among the top 10 countries for CO<sub>2</sub> emissions, possesses substantial oil and natural gas resources and seeks to meet the majority of its national energy needs through the provision and utilization of fossil fuels. Recently, there has been a notable shift from oil products to natural gas, with the residential sector now accounting for approximately 75% of total energy consumption (Farajzadeh & Nematollahi, 2018). Despite being a large country with access to various environmentally friendly natural energy sources like solar and wind power (Moshiri, 2015). Iran's current policies are leading to an increase in CO<sub>2</sub> emissions, and there is still no certain and substantial strategy for the adoption of renewable energy sources (Hosseini et al., 2019).



**Figure 21.** CO<sub>2</sub> emissions of Iran’s residential sector and growth rate. (Created by the author)

## 3.2. Data

The investigation's data comprises two sections. In the first section, Iran's provinces are categorized interested in four groups centered on income and population, following an ad hoc approach. Tables 3 and 4 illustrate the grouping ranges according to the provincial averages for population and income. The twenty-eight provinces of Iran are segmented into four categories based on the averages of factors such as oil and gas consumption, electricity consumption, CO<sub>2</sub> emissions, income, and population. These categories are classified as very low, below average, above average, and very high. Specifically, appendix 1 presents the provincial groupings according to income.

This division based on mean and standard deviation helps to identify potential disparities between high- and low-income provinces. Appendix 1 presents categorization based on income, using the same approach of mean and standard deviation. According to appendices 1 and 2 Provinces with similar populations, income and energy structures are grouped together, suggesting that better per capita equality correlates with improved conditions for these provinces. Furthermore, Tables 3 and 4 presents the range of categorization based on income and population.

During the study period, eight provinces exhibited unstable income situations, with Bushehr, Kohgiluyeh, West Azerbaijan, Mazandaran, and Markazi experiencing the most significant fluctuations. The income group analysis revealed that only Tehran was categorized in the fourth group, while over 50% of the provinces fell into the first group. Most large cities were classified within the third group. The income trends over the 17-year period indicated that the majority of provinces maintained a stable economic situation, implying that Iran's economic sector did not substantially contribute to household income growth. In this analysis, oil, gas, and electricity specifically gas oil, kerosene, and fuel oil are considered the primary fuels used in the household sector. Notably, more than ninety percent of electricity generation in Iran is derived from fossil fuels. Some provinces lack energy resources for agriculture and industry, while others are abundant in diverse energy sources. These resource disparities lead to varying household incomes across different provinces. Consequently, income inequality contributes to increased disparities in energy consumption and CO<sub>2</sub> emissions. appendix 2 categories provinces into four main groups based on population. Only three provinces Sistan, Kerman, and Hormozgan exhibited unstable populations, indicating that most provinces experienced consistent growth and remained in the same group. During the study period, Tehran emerged as the leading province in terms of both income and population, exacerbating inequality among the 28 provinces.

**Table 3.** The distribution of average-based population categories. (Created by the author)

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	1,466,015–2,404,109	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

**Table 4.** The distribution of average-based income categories (Trillion). (Created by the author)

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
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

The data in the second phase of the research are separated into two primary groups: the independent variables, which are additionally subdivided into four categories: climatic, energy, economic, and societal aspects; and the dependent variable, which is CO<sub>2</sub> emissions (in tons). Precipitation (mm), and climate parameters are Heating

Degree Days ( $^{\circ}\text{C}$ ), and Cooling Degree Days ( $^{\circ}\text{C}$ ). The variables in the energy subgroup include the following: the amount of oil consumed (in thousand liters), the amount of natural gas consumed (in  $\text{m}^3$ ), the amount of electricity consumed (in kWh), and the corresponding costs (in rials per liter,  $\text{m}^3$ , and kWh). The fuel group's consumer price index, which is indexed at 100 for 2016 as the base year, is used to alter these energy costs.

A dummy variable is included, marked with a value of 1 for the years when energy subsidies were removed (2010-2019) and 0 for the preceding period (2001-2010). household revenues (million Rial) is the sole economic part, modified in accordance with the 2016=100 general consumer price index. Social factors encompass family size (number of persons), educational rate (%), household employment rate (%), amount of buildings, and urbanization rate (%).

Data for all Iranian provinces were sourced Based on data from the Statistical Yearbook published by the Statistical Centre of Iran and the Energy Balance Sheets provided by the Ministry of Energy of Iran, covering the interval from 2001 to 2019. This period was chosen due to data availability. To address the issue of heteroscedasticity and to highlight the long-term expandable interaction among factors, every factors were converted into logarithmic quantities. Table 5 provides details on the variables, including their symbols, definitions, units and data sources.

**Table 5.** Overview of gathered data. (Created by the author)

<b>Variables Symbols</b>	<b>Definitions</b>	<b>Units</b>	<b>Sources</b>	
<b>Dependent</b>	Log c	Logarithm of CO <sub>2</sub> Emissions	Ton	Energy Balance Sheets <a href="https://irandatportal.syr.edu/energy-environment">https://irandatportal.syr.edu/energy-environment</a>
	Log t1	Logarithm of Heating Degree Days	C <sup>0</sup>	Iran Meteorological Organization and <a href="https://www.irimo.ir/power.larc.nasa.gov">https://www.irimo.ir/power.larc.nasa.gov</a>
<b>Independent</b>	Log t2	Logarithm of Cooling Degree Days	C <sup>0</sup>	Iran Meteorological Organization and <a href="https://www.irimo.ir/power.larc.nasa.gov/">https://www.irimo.ir/power.larc.nasa.gov/</a>
	Log pr	Logarithm of Precipitation	mm	Statistical Yearbook <a href="https://www.amar.org.ir/">https://www.amar.org.ir/</a>
<b>A) Climate</b>	Log oil	Logarithm of Oil Products Consumption	Thousand Liter	Energy Balance Sheets <a href="https://irandatportal.syr.edu/energy-environment">https://irandatportal.syr.edu/energy-environment</a>
	Log gas	Logarithm of Natural Gas Consumption	m <sup>3</sup>	Energy Balance Sheets <a href="https://irandatportal.syr.edu/energy-environment">https://irandatportal.syr.edu/energy-environment</a>
	Log elec	Logarithm of Electricity Consumption	Kwh	Energy Balance Sheets <a href="https://irandatportal.syr.edu/energy-environment">https://irandatportal.syr.edu/energy-environment</a>
	Log op	Logarithm of Oil Products Price	Rial per Liter	Energy Balance Sheets <a href="https://irandatportal.syr.edu/energy-environment">https://irandatportal.syr.edu/energy-environment</a>
	Log gp	Logarithm of Natural Gas Price	Rial per m <sup>3</sup>	Energy Balance Sheets <a href="https://irandatportal.syr.edu/energy-environment">https://irandatportal.syr.edu/energy-environment</a>
	Log ep	Logarithm of Electricity Price	Rial per Kwh	Energy Balance Sheets <a href="https://irandatportal.syr.edu/energy-environment">https://irandatportal.syr.edu/energy-environment</a>
	d	Dummy Variable for Energy Subsidy		Energy Balance Sheets <a href="https://irandatportal.syr.edu/energy-environment">https://irandatportal.syr.edu/energy-environment</a>
	<b>C) Economic</b>	Log i	Logarithm of Household Income	Million Rial
<b>D) Social</b>	Log s	Logarithm of Household Size	Person	Statistical Yearbook <a href="https://www.amar.org.ir/">https://www.amar.org.ir/</a>
	Log e	Logarithm of Educational Rate	%	Statistical Yearbook <a href="https://www.amar.org.ir/">https://www.amar.org.ir/</a>
	Log em	Logarithm of Household Employment Rate	%	Statistical Yearbook <a href="https://www.amar.org.ir/">https://www.amar.org.ir/</a>
	Log b	Logarithm of Building Stock	Number of Buildings	Statistical Yearbook <a href="https://www.amar.org.ir/">https://www.amar.org.ir/</a>
	Log u	Logarithm of Urbanization Rate	%	Statistical Yearbook <a href="https://www.amar.org.ir/">https://www.amar.org.ir/</a>

### 3.3. Inequality methods (Theil and Kaya Factor)

The research includes two methodologies the first of which is the Gini coefficient has limitations when it comes to measuring income inequality within a society. Generally, the Gini coefficient is a macroeconomic statistical measure that indicates the level of societal stratification in terms of the distribution of certain goods. Conversely, the Theil index is scale-invariant and remains unaffected by devaluation over time. The Theil index also satisfies the decomposability axiom, which allows it to break down inequality into within-group and between-group components (Tutberidze et al., 2018). The Theil index is a well-regarded metric for measuring inequality that has attracted considerable attention from researchers. While various tools exist for assessing inequality, the Theil index, developed in 1967, has remained a leading method in the field. This determine, according to (Bourguignon, 1979a), is the only population-weighted disparity index that satisfies the Pigou–Dalton requirement for calculating the inequality in CO<sub>2</sub> per capita emissions between territorial units, is distinguishable, symmetrical, and scale-invariant, and can be broken down into groups of data. The Theil index is considered a comprehensive measure of inequality, as noted by various scholars (Duro & Padilla, 2011), due to its ability to be fully deconstructed into multiple contributing variables. This decomposition provides valuable insights. Several researchers have developed methods to break down the Theil index interested in wages and population subdivisions. Additionally, inequality can be divided into within-group and between-group components using the Theil index, calculated as follows:

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

In Equation (1),  $S$  denotes the total number of provinces assessed. The term  $c_{i,t}$  refers to the proportion of various variables, including oil consumption, natural gas usage, carbon emissions, and electricity. Meanwhile,  $Q_{i,t}$  is a weighting factor, represented by the percentage of the province's total population (or income) at time  $t$ .

A drop in the Theil index designates a more uniform dispersal, while an increase signifies greater divergence among regions. This index measures the deviation in energy expenditure that cannot be described by revenue, population, or other weighting variables<sup>81</sup>. Other factors, such as climate and the economic structure of each province, contribute to this unexplained variation. In this analysis, regional grouping is based on household income, dividing Iran's 28 provinces into four income groups. The initial group consists of provinces with the minimal revenue, whereas the fourth group contains those through the greatest revenue. Additional classification is created by the geographical position of the provinces. The provinces are grouped into

regions  $P \leq N$ , denoted as  $R_g = R_1, \dots, R_P$ , with each province belonging to a single region,  $R_p$ , where  $g$  ranges from 1 to  $P$ . To determine the provincial breakdown of the Theil index, it is essential to determine the overall portion of each region by applying the following equation:

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

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

Equations (2) and (3) present the shares of region  $R_g$  relative to the total. Using these, the inequality within the region can be calculated as follows:

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

To determine the average within-group inequality, a weighted sum of the specific values within each region is necessary. This can be computed using the following equation:

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

The disparity between groups can be calculated in the following manner:

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

This section categorises the inequality in  $CO_2$  emission distribution into two types: disparity between provinces and disparity within provinces. This distinction enables researchers to examine whether the reduction in emission inequality stems from a decrease in the disparity between wealthy and poorer provinces, or if the change is due to a levelling of inequalities among provinces with similar income levels (Suh, 2018).

Consequently, the complete Theil index can be reformulated using the following equation:

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

In Equation (7),  $F_{w,t}$  measures inequality within the provinces of region  $g$ , whereas  $F_{B,t}$  captures the inequality among the  $G$  regions, emphasising the disparities between different groups of provinces. For comparison, the Theil index is also calculated using the intensity  $X$  for both population and income. This necessitates modifying Equation (8) as follows:

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

where  $H$  represents the average intensity of revenue or population, as well as  $CO_2$  emissions or energy consumption (including electricity, natural gas, and oil).

The “Kaya identity” model formulates a straightforward arithmetic calculation that combines environmental, economic and demographic factors to estimate  $CO_2$  emissions resulting from human actions, as demonstrated in Equation (9). This model provides a practical and effective method for quantitatively assessing how various significant factors influence changes in emissions or energy consumption. The Kaya identity can be expressed using the subsequent equation:

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

In this approach,  $CO_{2,i}$  represents the total carbon emissions of province “ $i$ ”,  $E$  represents the total energy consumption,  $I_i$  stands for household income, and  $POP_i$  refers to the population. These aspects collectively help in understanding the mechanisms driving changes in emissions, though they do not establish causality. Therefore, an increase in population does not necessarily lead to higher carbon emissions, just as a rise in revenue does not always result in increased emissions (Bianco et al., 2019).

According to the Kaya identity, Carbon emissions ( $CO_{2,i}/POP_i$ ) are defined as the product of three components: the carbon intensity of energy consumption ( $CO_{2,i}/E_i$ ), the energy intensity ( $E_i/I_i$ ), and the income per capita ( $I_i/POP_i$ ).

The first factor represents the fuel mix, the second illustrates energy efficiency and the sectoral structure of the economy, and the third measures economic productivity. To examine the inequality of  $CO_2$  emissions, the Theil index can be employed, as outlined in Equation (10):

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

In this context,  $p_i$  denotes the province's share of the total population,  $H_i$  represents carbon emissions, and  $\bar{H}$  indicates Iran's average carbon emissions. The Kaya identity is utilised to break down the Theil index, as established in Equation (10), in order to examine the origins of carbon emission inequality. Specifically, three vectors can be evaluated: one comprising individual variable values and the other two containing average values, as outlined below:

$$\chi_i^\alpha = \alpha_i * \bar{\beta} * \bar{\lambda} \quad (11)$$

$$\chi_i^\beta = \bar{\alpha} * \beta_i * \bar{\lambda} \quad (12)$$

$$\chi_i^\gamma = \bar{\alpha} * \bar{\beta} * \lambda_i \quad (13)$$

where  $\bar{\alpha}$ ,  $\bar{\beta}$  and  $\bar{\lambda}$  represent the provincial averages, which can be determined using the trailing equation:

$$\bar{H}^\alpha = \sum_{i=1}^N P_i * H_i^\alpha \quad (14)$$

The similar is applicable for  $\bar{H}^\beta$  and  $\bar{H}^\lambda$ . The degree of inequality for each element can be assessed using the Theil index, as seen in Refs (Padilla & Duro, 2013; Remuzgo & Sarabia, 2015).

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

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

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

These indices indicate the individual contribution of each element of the Kaya identity in the Iranian domestic sector: carbon intensity, energy intensity, and income per capita. For a complete decomposition, the relations terms must be included, as outlined in (Padilla & Duro, 2013), and can be computed as follows:

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

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

Where  $\sigma_{\alpha,\beta\lambda}$  represents the population-weighted covariance between carbon intensity and energy intensity, and  $\sigma_{\beta\lambda}$  denotes the population-weighted covariance linking energy intensity and income per capita. Consequently, the Theil index for carbon emissions can be expressed with the following equation:

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

Conversely, as noted by Remuzgo & Sarabia (2015), because understanding the interface terms can be opposing or inaccurate, the Shorrocks methodology assigns their impact to the three major relations (Padilla & Duro, 2013). This approach distributes the interaction terms evenly among the components from which they originate.

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

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

This can be rewritten as above.

### 3.4. Trend analysis models

To identify trends in the time series, the Mann-Kendall (MK) test is used in conjunction with Sen's Slope estimator developed by (Mann, 1945), were employed. The MK test is nonparametric, making it resilient to outliers and effective at detecting

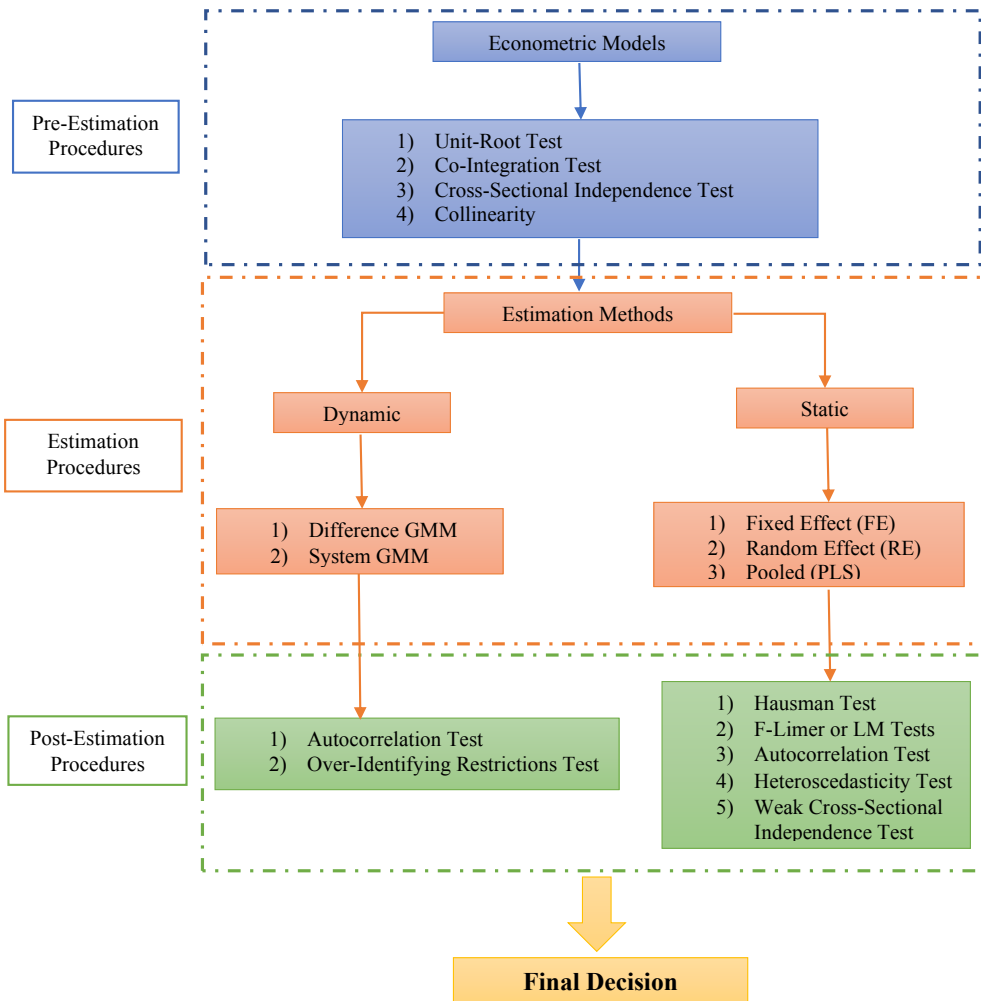
trends in data series. In this test, the null hypothesis (H0) posits that no trend exists in the series, whereas the alternative hypothesis (Ha) indicates that a trend is present. The test statistic S can be calculated as follows:

$$S = \sum_{j=1}^{n-1} \sum_{k=j+1}^n \text{Sign} (y_k - y_j) \quad (23)$$

Where, n = Total observations,  $y_k$  and  $y_j$  represent the data point where  $k > j$ .

### 3.5. Econometric methods

The second part of the methodology involves the use of econometric models to investigate the impact of energy expenditure and domestic socio-economic circumstances on CO<sub>2</sub> emissions. Numerous studies have employed a variety of methodologies to examine these causes (Balezentis, 2020a; J. Chen et al., 2022; Q. Li et al., 2020; Yang et al., 2020). The LMDI decomposition model has been used to assess the effects of population growth, economic expansion, and energy use on household CO<sub>2</sub> emissions. The impacts of energy use and household socioeconomic characteristics on CO<sub>2</sub> emissions are frequently studied using econometric models, particularly panel and cross-sectional data analysis techniques (Bai et al., 2019; Y. Chen & Jiang, 2022; Chun-sheng et al., 2012; Donglan et al., 2010; Imran et al., 2022; Karpinska & Śmiech, 2022; Q. Li et al., 2020; Meangbua et al., 2019; Miao, 2017; Miao, Gu, Zhang, Zhen, et al., 2019; Y. Wang & Zhao, 2018). Other studies, such as (Xu et al., 2015) used ANOVA examination method. Likewise, in order to investigate the effects of energy, climate, and household socioeconomic characteristics on CO<sub>2</sub> emissions throughout Iran's provinces between 2001 and 2019, we used panel regression. Unlike previous studies, we used both static and dynamic panel regression methods to enhance the accuracy and depth of our estimations. To achieve this, we developed a methodological framework to clarify the estimation procedures. As depicted in Fig. 22, the entire process is divided into three main steps: pre-estimation, estimation, and post-estimation procedures.



**Fig 22. Research approach Framework**

Source: authors' elaborations

We used both static and dynamic panel models to investigate the effects of domestic socioeconomic attributes, energy, and climate on CO<sub>2</sub> emissions. Equations 24 and 25 present the formulation of the given static and dynamic equations:

$$\begin{aligned} \log c_{i,t} = & \alpha_0 + \alpha_1 \log t_{1,t} + \alpha_2 \log t_{2,t} + \alpha_3 \log pr_{i,t} + \alpha_4 \log oil_{i,t} \\ & + \alpha_5 \log gas_{i,t} + \alpha_6 \log elec_{i,t} + \alpha_7 \log op_{i,t} + \alpha_8 \log gp_{i,t} \\ & + \alpha_9 \log ep_{i,t} + \alpha_{10} \log i_{i,t} + \alpha_{11} \log s_{i,t} + \alpha_{12} \log e_{i,t} \\ & + \alpha_{13} \log em_{i,t} + \alpha_{14} \log b_{i,t} + \alpha_{15} \log u_{i,t} + \alpha_{16} D_{i,t} + \alpha_{17} Z_{i,t} \\ & + \varepsilon_{i,t} \end{aligned} \quad (24)$$

$$\begin{aligned} \log c_{i,t} = & \beta_0 + \beta_1 L \log c_{i-p,t} + \beta_2 \log t_{1,t} + \beta_3 \log t_{2,t} + \beta_4 \log pr_{i,t} \\ & + \beta_5 \log oil_{i,t} + \beta_6 \log gas_{i,t} + \beta_7 \log elec_{i,t} + \beta_8 \log op_{i,t} \\ & + \beta_9 \log gp_{i,t} + \beta_{10} \log ep_{i,t} + \beta_{11} \log i_{i,t} + \beta_{12} \log s_{i,t} \\ & + \beta_{13} \log e_{i,t} + \beta_{14} \log em_{i,t} + \beta_{15} \log b_{i,t} + \beta_{16} \log u_{i,t} \\ & + \beta_{17} D_{i,t} + v_{i,t} \end{aligned} \quad (25)$$

The variables *i* and *t* represent the province and the time period between 2001 and 2019. The coefficients  $\alpha$  and  $\beta$  are associated with different types of variables previously defined. *Z* denotes an individual-specific effect, while both  $\varepsilon$  and *v* are error terms. *L* represents the lag operator, while *p* is the lag order.

To determine whether the panel data has a unit-root (Im et al., 2003; K Hadri, 2000; Levin et al., 2002; Maddala & Wu, 1999; panels et al., 2001; Pesaran, 2007, 2008) created a large number of standard and customized panel unit-root tests. Any of them, other from Hadri's examination, are made to investigate the unit-root in a panel's null hypothesis. Rather, the alternative hypothesis is a contentious matter. Cross-Sectional Augmented Dickey-Fuller panel unit-root test was employed in the investigation, It was advanced by (Pesaran, 2007) to verify the presence of unit-root in the particular panel data. Because the CADF test is insensitive to sample size, cross-sectional dependence, and the type of data set (balanced or unbalanced), we chose it. The CADF test utilized to each single series. The CADF regression is defined as Eq (26):

$$\Delta Y_{i,t} = \alpha_i + \theta_t^* Y_{it-1} + d_0 \bar{Y}_{t-1} + \sum_{j=0}^p d_{j+1} \Delta \bar{Y}_{t-j} + \sum_{j=1}^p \gamma_{ij} \Delta \bar{Y}_{it-j} + u_{it} \quad (26)$$

*Y* represents the observation on the *i*-th cross-section unit at time *t*, and  $\bar{Y}$  is the mean of *Y*, *P* across all cross-section units representing the lag order, while  $\alpha_i$ ,  $\theta_t$ ,  $d_0$ , and  $\gamma_{ij}$  are coefficients. The null hypothesis and alternative hypothesis for the CADF unit-root test are specified. (Hashmi & Alam, 2019; Pesaran, 2007):

- $\left\{ \begin{array}{l} H_0: \theta_t = 0 \\ H_a: \theta_t < 0 \end{array} \right.$
- The null hypothesis suggests that all the series under consideration are non-stationary processes. According to the alternative theory, every series is a stationary process.

In order to examine the long-term co-integration of a model's variables, a number of testing techniques, such as (Kao, 1999a; Pedroni P, 2004; Westerlund, 2007), are available. We used the Kao test in the study to look at the long-standing co-integration between the two models' series. On the first stage of regression, the Kao test specifies the homogeneous coefficients as well as the cross-section intercept. The replacement hypothesis supports the long-standing co-integration, while the null hypothesis states that there is no long-run co-integration midst the series. For a regression as Eqs (27,28), the ADF test is as follows:

$$Y_{it} = \beta X_{it} + \theta Z_{it} + u_{it} \quad (27)$$

$$ADF = \frac{t_{ADF} + \frac{\sqrt{6N} \cdot \hat{\sigma}_v}{2\hat{\sigma}_{0v}}}{\sqrt{\frac{\hat{\sigma}_{0v}^2 + 3\hat{\sigma}_v^2}{2\hat{\sigma}_v^2 + 10\hat{\sigma}_{0v}^2}}} \quad (28)$$

Where,  $Y, X, Z$ , and  $u$  are the dependent variable, independent variable, intercept, and the error term, respectively.  $\theta$  and  $\beta$  are coefficients.  $t_{ADF}$  is the  $t$  statistic of  $\rho$  (the pair-wise correlation of the residuals). Also,  $\hat{\sigma}_{0v}^2$  and  $\hat{\sigma}_v^2$  stand for the long-run and simple variance of error terms (Kao, 1999a; Kasman & Duman, 2015).

A Cross-Sectional Dependence (CSD) is used to determine whether there is cross-sectional relying on the panel data across the variables. The introduction of a novel cross-sectional dependence test by (Pesaran, 2007), the test keeps constant on a certain spatial weight matrix, regardless of how big or small the sample is. Units are cross-sectionally uncorrelated under the test's null hypothesis, while serial correlation exists under the alternative hypothesis. The CD statistic for the panel data model in Eq (26) is measurable as Eq (29).

$$CD = \sqrt{\frac{2T}{N(N-1)}} \left( \sum_{i=1}^{N-1} \sum_{j=i+1}^N \hat{\rho}_{ij} \right) \quad (29)$$

Where,  $\rho$  is the sample estimate of the pair-wise correlation of the residuals (Dehdar et al., 2022; Hashmi & Alam, 2019; Pesaran, 2021).

The relationship concerning independent variables in a model is described statistically by a concept called multicollinearity, which reduces the reliability of statistical conclusions. Multicollinearity between the variables is an important factor to consider when estimating stable parameters in the model. In various ways, a high degree of multicollinearity concerning variables will make the model more complex to evaluate the relationship relating them. Designed for this, evaluating the degree of multicollinearity among model variables in the econometric model can be accomplished with the use of the Variable Inflation Factor (VIF). In general, no correlation exists between the variables when the VIF value is 1.

$$VIF = \frac{1}{1 - R^2} \quad (30)$$

The variables are considered highly associated if their VIF falls between 1 and 5, and extremely correlated if their VIF exceeds 5. Significant multicollinearity between variables necessitates additional research when the VIF is greater than 10. In the present investigation, the multicollinearity across the variables was tested using VIF as Eq (30), (Kim, 2019; N Shrestha, 2020).

### **3.6. Estimation methods**

#### **3.6.1. Static estimation models**

Static and dynamic estimating approaches are the two basic assessment strategies used in panel data regression. The Fixed Effect (FE), Random Effect (RE), and Pooled (PLS) procedures make up the static panel regression categories. The way heterogeneity has been imposed in the models varies among the estimating techniques. The most basic and straightforward estimation model, known as pooled regression (PLS), has a single intercept for every panel unit. In exchange, heterogeneity is enacted in the form of random factors and individual-specific effects for both the FE and RE models. More specifically, the FE regression model allows for the intercept to be associated with the dependent variable and to change freely across people or groups. When confronted by a large sample size (N) and short time dimensions (T), the FE model could be utilized instead of the RE model. The individual-certain effect in a regression model called RE is a random variable that is not thought to be associated with the independent variables. All three static panel estimating techniques PLS, FE, and RE, are formulated as Eq (31) to Eq (33), respectively.

$$Y_{it} = \alpha + \beta X_{it} + \varepsilon_{it} \quad (31)$$

$$Y_{it} = \alpha_i + \beta X_{it} + \varepsilon_{it} \quad (32)$$

$$Y_{it} = \alpha + \beta X_{it} + v_i + \varepsilon_{it} \quad (33)$$

where the independent and dependent variables are X and Y. The coefficients are denoted by  $\alpha$  and  $\beta$ . Error terms, random factor, province, and time period are represented by the symbols  $\varepsilon$ ,  $v$ ,  $i$ , and  $t$ , respectively (Bell & Jones, 2015; Meangbua et al., 2019; Pakrooh et al., 2021; Puntoon et al., 2022).

By the initial phase, the Hausman test was used to determine whether to select the FE or RE in order to verify the accuracy of the estimated model. The test's null hypothesis is that the regressors and effects do not autocorrelated. On the other hand, the alternative theory holds that regressors and impacts are related. Put otherwise, the alternative hypothesis is supported by FE and the null hypothesis by RE. The Hausman test is described as Eq (34).  $\beta_1$  and  $\beta_0$  are the vector of coefficients under the null and alternative hypotheses, respectively.

Then, in order to make a final selection on a suitable model, we must do the F-Limer or the LM (Breusch-Pagan) tests, Eqs. (35) and (36), in order to differentiate between the model that was chosen in the preceding stage and PLS. F-limer is the statistical test that is frequently used to compare statistical models and determine which model best fits the sampled data. In the test,  $R_{FE}^2$  and  $R_{RE}^2$  are R-squared of the FE and RE estimation models. We can perform a PLS model regression If the RE's variance is zero, which suggests that each panel unit has the same intercept, then the null hypothesis for the LM test would be valid. Contrarywise, the alternate assumption rejects zero variance for all panel units (Greene, 2012; Meangbua et al., 2019; Pakrooh et al., 2021).

$$H = (\beta_1 - \beta_0)'[\text{var}(\beta_0) - \text{var}(\beta_1)]^{-1}(\beta_1 - \beta_0) \quad (34)$$

$$F = \frac{(R_{FE}^2 - R_{RE}^2)(n-1)}{(1-R_{FE}^2)(nt-n-k)} \quad (35)$$

$$LM = \frac{NT}{2(T-1)} \left[ \frac{\sum_{i=1}^N (T \bar{e}_i)^2}{\sum_{i=1}^N \sum_{t=1}^T e_{it}^2} - 1 \right]^2 \quad (36)$$

Important problems in the error terms of panel regression models include heteroscedasticity, weak cross-sectional independence, and serial autocorrelation. We used the Lagrange test for heteroscedasticity, the Pesaran test for cross-sectional

independence in error terms, and the Wooldridge test for serial autocorrelation in this regard. In the event that the model's shortcomings are revealed by the findings, the outcome would be objective and ineffective. Feasible Generalized Least Square (FGLS) estimate is used to address these issues introduced by (Hansen, 2007), and all those issues are immediately considered in the estimation process by the approach. This technique permits estimate in the error terms of a panel regression model with first-order autocorrelation, heteroscedasticity, and weak cross-sectional correlation. This method involves a two-step procedure to estimate the covariance matrix of error terms. Using the OLS approach, the anticipated residuals are obtained in the primary stage. The matrix is then re-estimated to produce the new residuals using OLS (Berezvai et al., 2022; Greene, 2012; Kostakis et al., 2021; Muzayanah et al., 2022; Pesaran, 2021; Wooldridge, 2010).

### 3.6.2. Dynamic estimation models

In the realm of economics, dynamic panel data methodology is one of the most often used and beneficial instruments, especially for energy and environmental study. Compared to static models, dynamic panel data model estimators have a few advantages, such as the ability to handle individual heterogeneity and the utilization of many instrumental factors to address the endogeneity issue. The Difference Generalized Method of Moments (GMM), the first dynamic model estimator, was first presented by (Arellano & Bond, 1991), and later on, the System Generalized Method of Moments (GMM), the second estimator, was created by (Arellano & Bover, 1995). The Difference GMM estimator uses lags in differences as instruments, whereas the System GMM estimator employs both lags in differences and levels as instruments. Both estimators are suited for scenarios with large( N ) (many units) and short ( T ) (few time periods) panels. To clarify, consider Eq (37) a general dynamic model.

$$Y_{it} = \alpha + \gamma Y_{it-p} + \beta X_{it} + u_{it} \quad (37)$$

Where,  $Y$  and  $X$  are dependent and independent variables.  $\alpha$ ,  $\beta$ ,  $\gamma$  refer to coefficients.  $\varepsilon$ ,  $i$ ,  $t$ , and  $p$  are error terms, province, time dimension, and lag order (Hassan & Nosheen, 2019; Ito, 2017; Labra et al., 2018; Muhammad, 2019; Roodman, 2009).

In the model, using a lot of instruments is a sign of overidentification. In relation to this issue, the Sargan and Hansen tests, which were introduced by (JD Sargan, 1958), are employed to verify that there are sufficient instrumental factors and that overidentification is not occurring. The validity of the methods used in the analysis of the one-step estimations is confirmed by the Sargan test. However, the Hansen test

is advised to verify overidentification in two-step calculations. The validity of all overidentification limitations is the null hypothesis in both the Sargan and Hansen tests. However, the alternative hypothesis assumes the presence of invalid instruments. To test for serial autocorrelation in dynamic panel models, the Arellano and Bond test is recommended. The null hypothesis for this test posits that no autocorrelation exists in the model. On the contrary, the alternative hypothesis stands with autocorrelation problem (Labra et al., 2018; Roodman, 2009).

## 4. Results and discussion

### 4.1. Descriptive results

Throughout the 19-years study period, household consumptions were divided into four groups based on the amount that was consumed in each of the three categories (oil, gas, and electricity). Each province was divided into four categories according to its level of consumption; the provinces with the lowest levels of consumption were in group 1, and the provinces with the highest levels of energy use were in group 4. Furthermore, provinces with medium and high consumption were included in groups 2 and 3. Figure 23 depicts the income pattern, which varied greatly over the 19 years, with a notable increase from 2010 to 2014. After that, there was a noticeable decline until 2017. After 2017, income showed a dramatic increase in 2018 and 2019, particularly in Group 4, which included Tehran and Khuzestan provinces. During the study period, the income level in group 4, which included Tehran and Khuzestan, exhibited signs of instability, with both rising and falling trends. Notably, Khuzestan dropped to group 3 after 2007 and remained there until 2017, before re-joining group 4 again in 2018 and 2019. Iran's economy has been trending downhill and extremely unstable in this regard in recent years.

Provinces with high revenues are included in Group 3, which exhibits a modest increase up until 2013. After that, a falling tendency is seen. group 1, which consists of a number of low-income provinces, had an upward trend from 2001 to 2007, but there was a dip in 2008 and 2009. After that, the trend rose until 2013 before declining till 2017. However, after 2017 again increased in 2018 and 2019. Throughout the study period, group 2, which consists of provinces with medium income levels, exhibits the same tendency as group 1.

Figure 24 presents data on Iran's population growth between 2001 and 2019. Throughout the research period, the population grew consistently and was similar in all the groups, with group 3 comprising the majority of the population. Only Tehran is included in population group 4, yet its population was greater than or equal to that of the other 13 provinces. Seven significant provinces compose group 3, which is home to over 50% of Iran's total population. Thirteen provinces make up group 1, with a combined population of roughly 12.2 million in 2001 and 15.5 million in 2019. group 2's population decreased from 13 million in 2001 to 8 million in 2019. Several provinces experienced population growth and moved up to group 3, while some others showed a population decline and dropped to group 1.

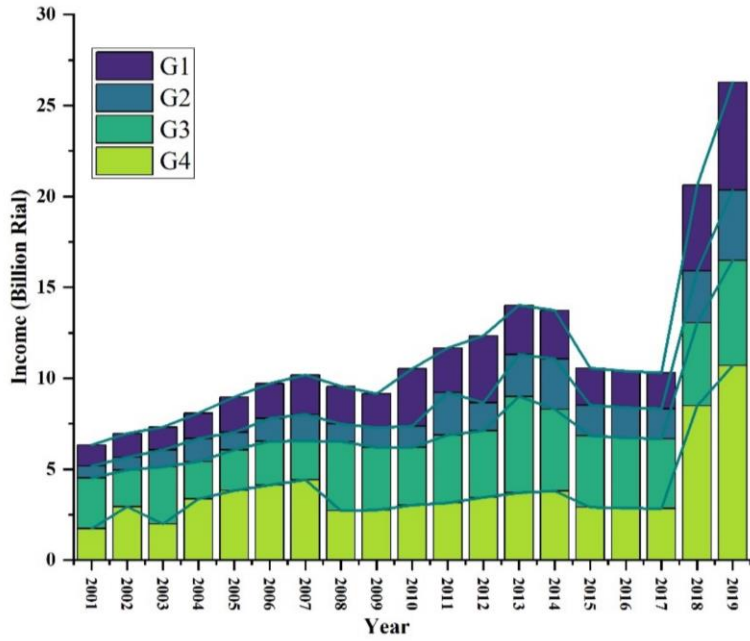


Figure 23. Patterns of real income . (Created by the author)

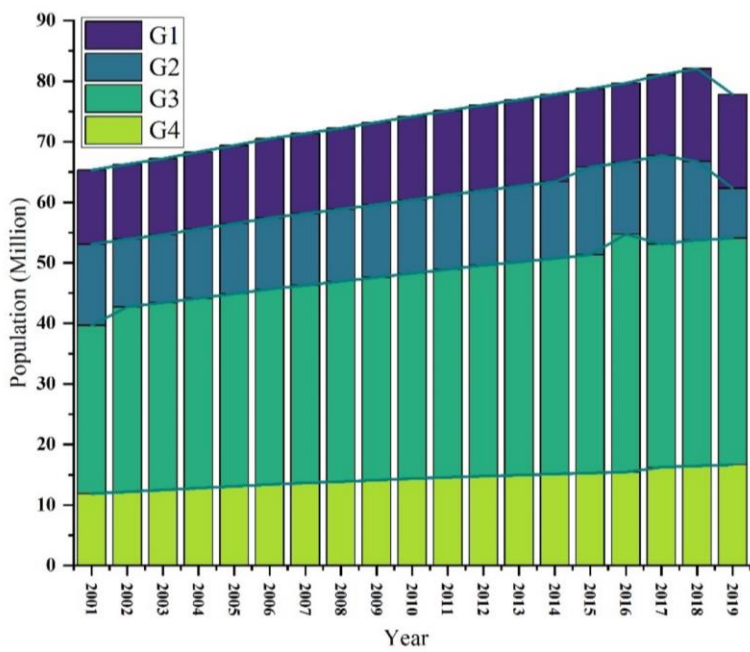
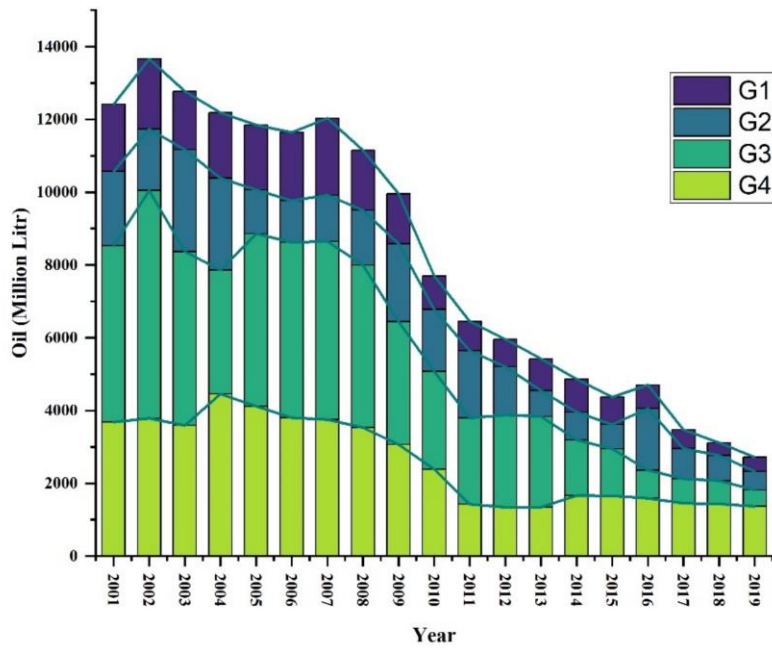


Figure 24. Tendency of population. (Created by the author)

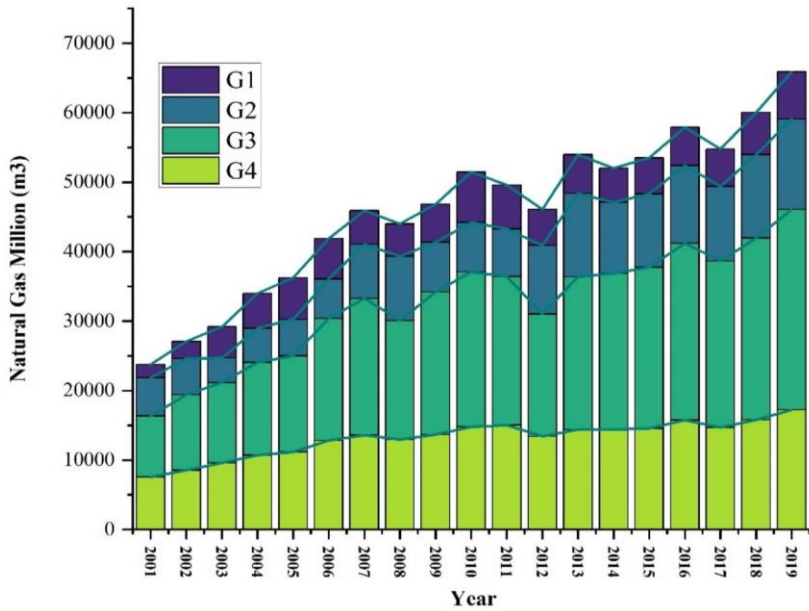
The trends in oil, gas and electricity use are shown in Figures 25-27. There may have been a decrease in the consumption of energy (oil, gas, and electricity) following the implementation of the subsidy-targeting program in 2010 and 2013. Figure 25 illustrates how oil usage was high at the start of the first eight years (2001–2009) but significantly decreased. Additionally, group 3 has the largest consumption. Group 3's consumption fell to between 96 and 330 million litres in 2019 from between 483 and 1337 million litres in 2001. Group 4's oil usage dropped from between 1337 and 2192 million litres in 2001 to between 330 and 563 million litres in 2019. However, group 4 consisted only of Tehran and West Azerbaijan.

Figure 26 illustrates the gradual increase in natural gas usage over the 19-year period. Groups 1 and 2 show the lowest energy use throughout this investigation, while groups 3 and 4 have the highest proportions. Group 1 comprises 12 provinces, where residential consumption in 2001 ranged from 0 to 424 m<sup>3</sup>. In 2019, consumption ranged from 8.6 to 1180 m<sup>3</sup>, with 11 provinces falling into group 1. Most provinces in group 1 lacked the gas infrastructure found in Sistan and Baluchestan and Hormozgan. In 2001, Tehran was the only province in group 4, with a consumption of 7,544 m<sup>3</sup>, and by 2019, it remained the only province in group 4, with an increased consumption of 17,252 m<sup>3</sup>. Group 3, comprising the provinces of East Azerbaijan, Khorasan, Esfahan, Gilan, and Mazandaran, had the highest percentage of gas consumption in 2001, ranging from 848 m<sup>3</sup> to 4,196 m<sup>3</sup>, with a combined consumption of 8,814 m<sup>3</sup>. By 2019, consumption in Group 3 ranged from 2,353 to 9,802 m<sup>3</sup>, covering seven provinces and totalling 28,826 m<sup>3</sup>. Overall, the number of gas consumers increased over time, leading to a corresponding rise in gas consumption.

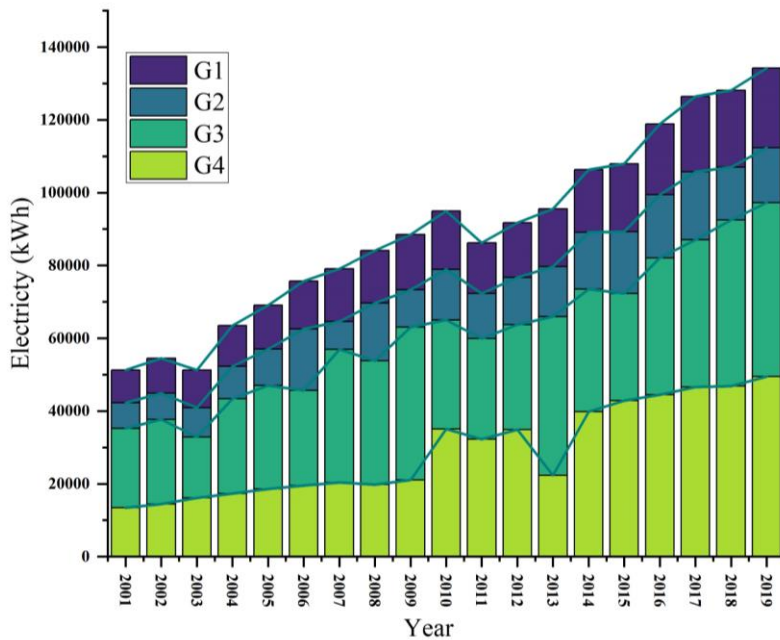
As seen in Figure 27, the amount of electricity consumed rose between 2001 and 2009, then declined somewhat until 2012, when it continued a moderate climb until 2019. Furthermore, group 3 accounted for the majority of household electricity consumption. In 2001, the total quantity of power consumed was 13,434 kWh in Group 4 (which included one province), 21,762 kWh in Group 3 (which included seven provinces), and 8946 kWh in Group 1, which included 15 provinces. In 2019, energy consumption in Groups 1 to 4 was 21,849 kWh, 15,150 kWh, 47,783 kWh, and 49,442 kWh, respectively, with these groups comprising 15, 4, 7, and 2 provinces. The advent of modern electrical devices in recent years such as phones, computers, home appliances, Bitcoin mining and heaters has enhanced the quality of life for many people in Iran. However, this improvement in living standards has also led to a significant rise in household electricity consumption.



**Figure 25.** The flow of petroleum product consumption. (Created by the author)

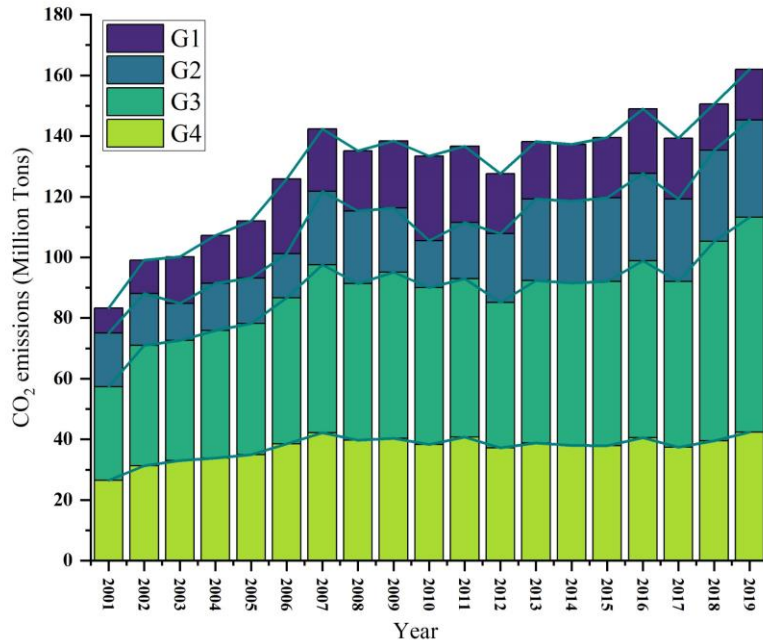


**Figure 26.** The trajectory of natural gas consumption. (Created by the author)



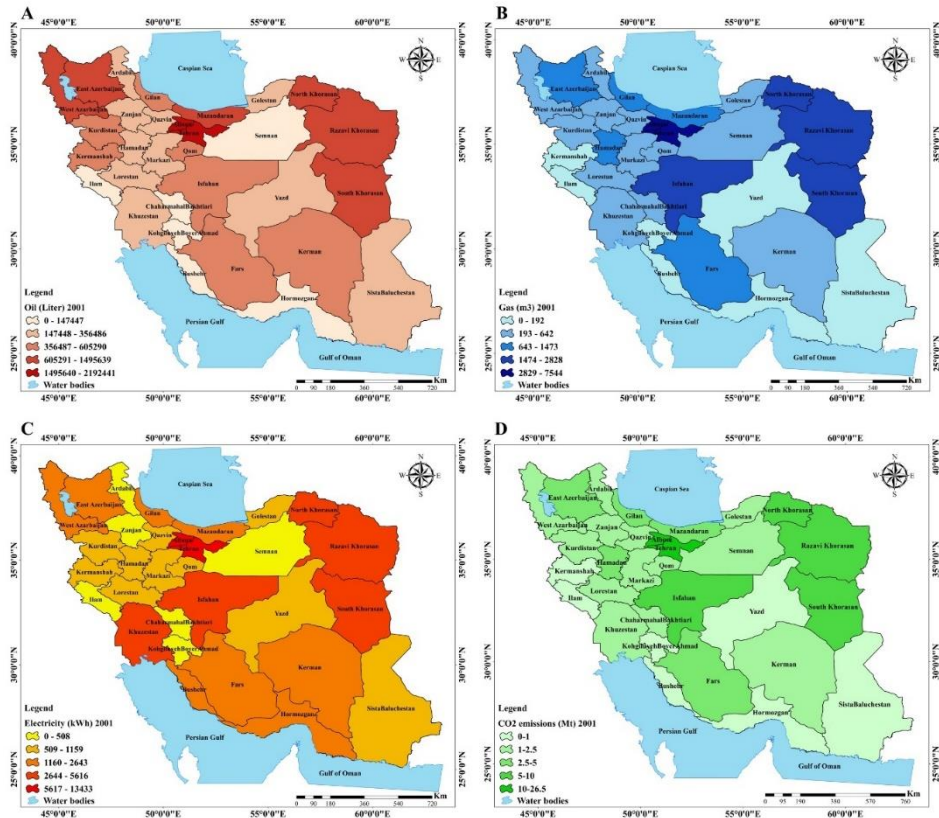
**Figure 27.** The tendency of electricity consumption. (Created by the author)

The CO<sub>2</sub> emissions, which grew gradually during the study period, are depicted in Figure 28. From 2007 to 2019, there was a small fluctuation. Additionally, group 3 had the greatest levels of CO<sub>2</sub> emissions out of groups 1, 2, 3, and 4. 30 million tons were produced in 2001 in large regions including West Azerbaijan, Esfahan, Khorasan, and Gilan; by 2019, the same provinces had 70 million tons. In 2001, Tehran, the sole member of group 4, produced the highest amount of CO<sub>2</sub> at 26 million tons, which increased to 42 million tons by 2019. Groups 1 and 2 emitted 8 million and 17 million tons of CO<sub>2</sub> respectively in 2001, and these figures rose to 16 million and 32 million tons by 2019. The provinces with the lowest CO<sub>2</sub> emissions included Ilam, Bushehr, Charmahal, Sistan and Baluchestan, Kurdistan, Kohgiluyeh and Boyer Ahmad, Hormozgan, and Yazd, all of which are relatively marginal and underdeveloped areas.



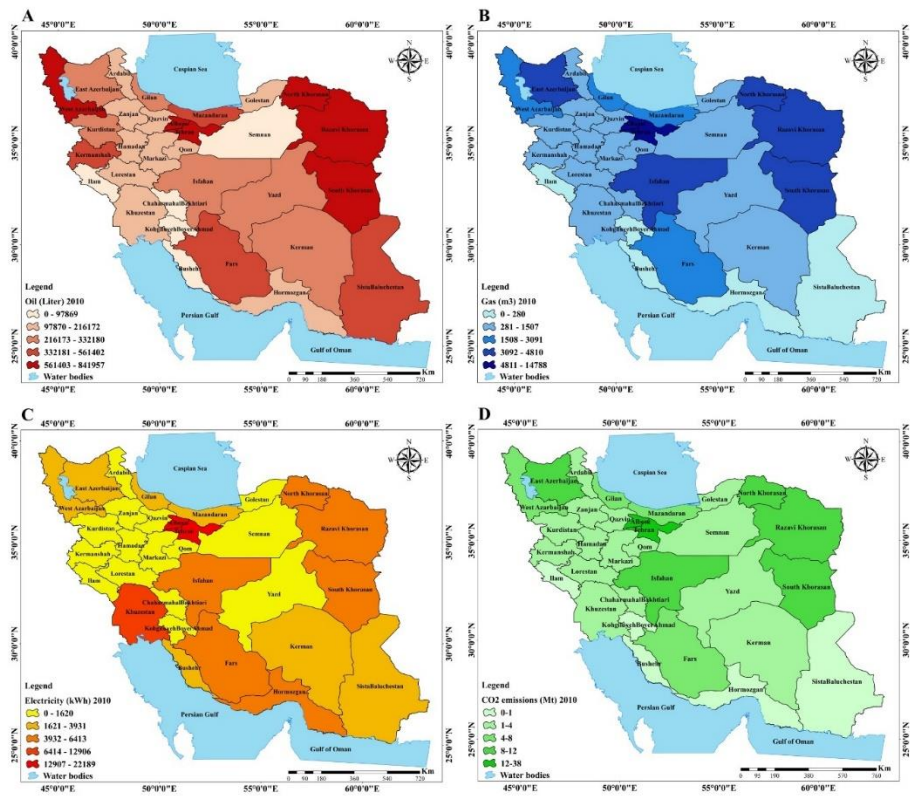
**Figure 28.** The pattern of CO<sub>2</sub> emissions. (Created by the author)

Given to Iran's unique topography, climate, cultural variety, and economic climate, regional study is vital. As a result, this investigation looked into energy usage and the impact of several variables on regional CO<sub>2</sub> emissions. Figure 29 illustrates the spatial distribution of energy consumption in the residential sector in 2001, encompassing oil, gas, and electricity. Notably, the provinces of Khorasan, Tehran, and Azerbaijan had a notably high proportion of oil consumption in this sector. Additionally, the majority of the southern provinces had very little gas consumption or none at all, while Khorasan, Tehran, and Isfahan had tremendous gas consumption. Group 1 provinces had a high percentage of electricity consumption (see to Figure 32). Conversely, provinces with extremely low electricity consumption included Semnan, Ardebil, Zanjan, Chaharmahal, and Bakhtiari, as well as Kohgiluyeh and Boyer-Ahmad. Regarding the 2010 oil, gas, and electricity use, map D of Figure 29 demonstrates that Group 1 provinces had a disproportionately large percentage of CO<sub>2</sub> emissions, whereas group 3 and group 4 provinces had a relatively low share of CO<sub>2</sub> emissions.



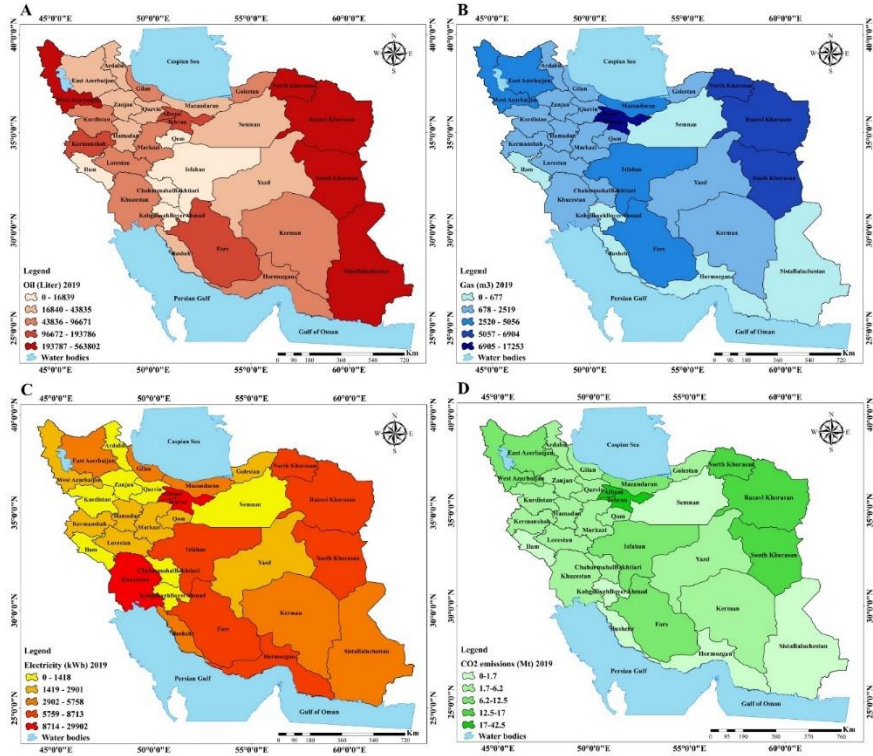
**Figure 29.** Map of Spatial distribution: (A) oil usage (2001), (B) gas usage (2001), (C) electricity usage (2001), (D) CO<sub>2</sub> emissions (2001). (Created by the author)

Figure 30 shows the geographical distribution of CO<sub>2</sub> emissions, electricity, gas, and oil consumption in Iran's residential sector in 2010. Due to the gas transition, the overall amount of oil consumed decreased significantly; nevertheless, the portion of oil expenditure in regions such as Tehran, Khorasan, East Azerbaijan, and Sistan and Baluchestan remained significant. The total amount of gas consumed rose significantly as compared to 2001. With the exception of the southern provinces, which were still without access to a pipeline for the residential sector, the portion of gas in the bulk of provinces in 2010 was developed than it was in 2001, thanks to the growing infrastructure in the gas sector. Additionally, the percentage of total electricity use rose. The provinces in the south consumed the most electricity, but Tehran and Khuzestan consumed the most overall. Group 1's large municipalities and regions (Figure 32) continue to emit a lot of CO<sub>2</sub>.



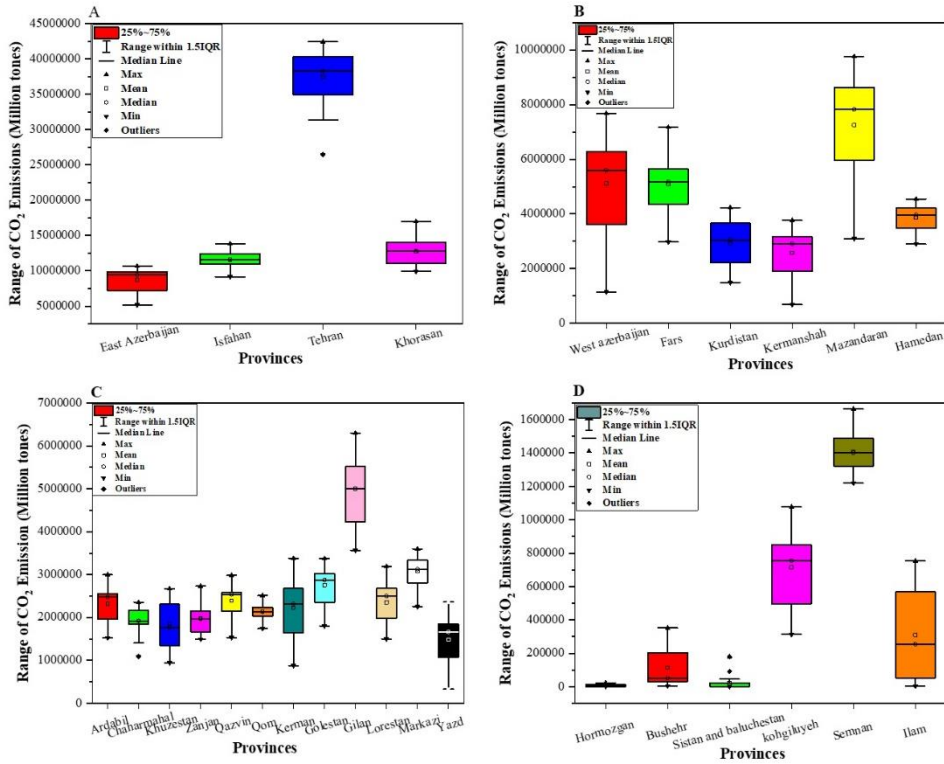
**Figure 30.** Map of spatial distribution: (A) oil usage (2010), (B) gas usage (2010), (C) electricity usage (2010), (D) CO<sub>2</sub> emissions (2010). (Created by the author)

Figure 31 illustrates the final year of this analysis, 2019. Oil consumption continued to decline, but it remained high in provinces without access to gas, such as Khorasan, Sistan and Baluchestan, and West Azerbaijan. Unlike in 2010, Tehran no longer had one of the utmost oil expenditure rates, thanks to better access to gas resources. Electricity expenditure patterns were similar to 2010, with the largest shares in major provinces and the southern regions. CO<sub>2</sub> emissions intensified in 2019 associated to 2010, with group 1 regions contributing significantly. In contrast, group 4 provinces had some of the lowest CO<sub>2</sub> emissions.



**Figure 31.** Map of Spatial distribution: (A) oil usage (2019), (B) gas usage (2019), (C) electricity usage (2019), (D) CO<sub>2</sub> emissions (2019). (Created by the author)

Figure 32 categorizes regions into four groups centered on CO<sub>2</sub> emissions. Group 1 (A) includes provinces with the ultimate CO<sub>2</sub> emissions, such as Khorasan, East Azerbaijan, Tehran and Isfahan, which have large populations and numerous industrial establishments. Group 2 (B) consists of six developing provinces with above-average CO<sub>2</sub> emissions. Group 3 represents provinces with average CO<sub>2</sub> emissions, including the bulk of provinces like Yazd, Golestan and Ardebil. Group 4 comprises provinces with the minimal CO<sub>2</sub> emissions, primarily located in the southern part of Iran. The following grouping highlights the regional differences in CO<sub>2</sub> emissions across the country.



**Figure 32.** The range of CO<sub>2</sub> emissions between specified groups of provinces in Iran: (A) group one, (B) group two, (C) group three, (D) group four. (Created by the author)

## 4.2. Trend analysis

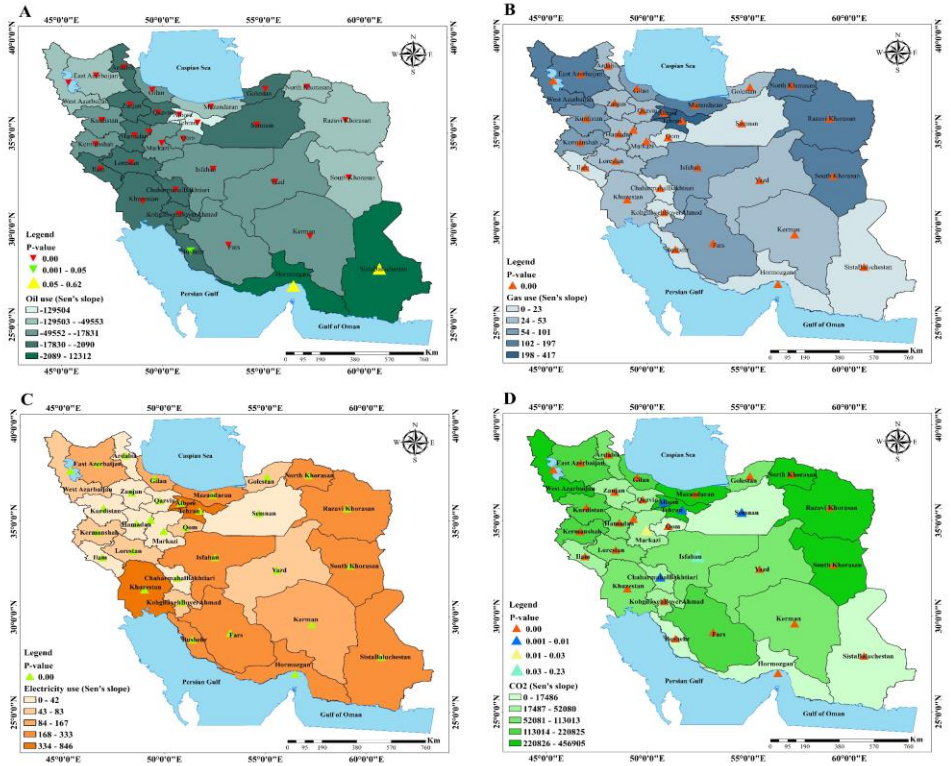
The trend analysis results in Figure 33 and appendices 3 to 6 show that different fuels consumption and CO<sub>2</sub> emissions Sen's slope and P-value among provinces of Iran. Figure 33 A and appendix 3 represent oil usage which indicates negative Sen's slope values for all provinces. Hormozgan is the only province that is not significant concerning its Sen's slope. Notably, Sistan and Baluchestan and Hormozgan are the only provinces with a positive trend, showing a Sen's slope value of 12,312, 1557.9091 respectively. Most of the provinces showed reduction in Oil use. However, some provinces represent dramatically reduction during study period according appendix 3, Tehran solely with Sen's slope -129504, recorded a tremendous decrease. With Kendall's tau at -0.9883 ( $p < 0.0001$ ). Provinces such Khorasan, Mazandaran and both Eastern and western Azerbaijan are in the second group of reduction based

on Figure 33 map A and appendix 3 with Sen's slope -53470.54, -60913.52, -49553.87 and -64596.8 respectively.

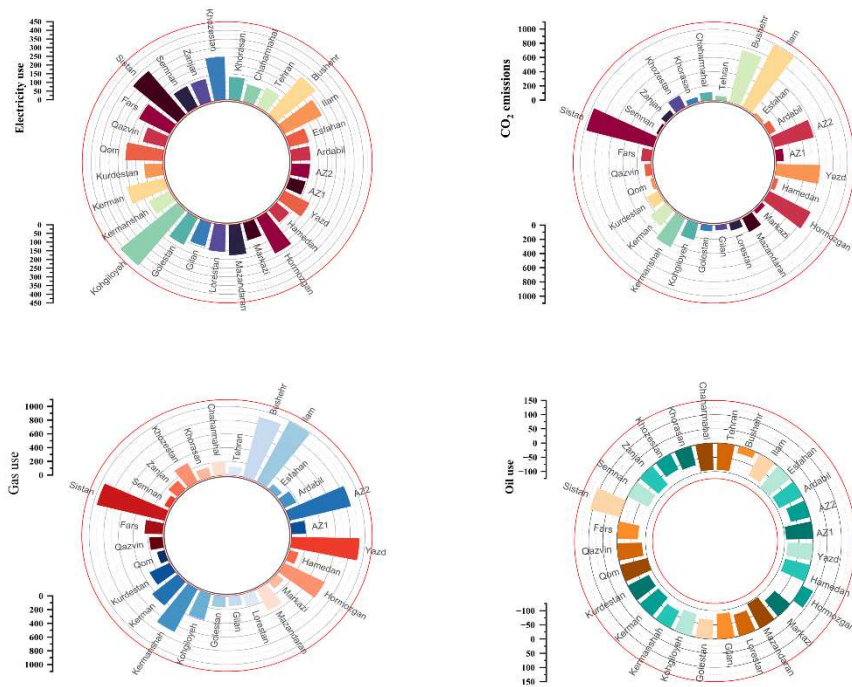
In terms of gas usage, according Figure 33 (B) and appendix 4 all provinces show a positive trend, with Tehran having the highest Sen's slope value at around 417. While some provinces exhibit a positive trend, the amounts are extremely low, including Sistan and Baluchestan, Hormozgan, Chaharmahal and Bakhtiari, Bushehr, and Ilam with Sen's slope 0.7214, 0.40, 23.6, 6.95, 19.12 respectively.

As illustrated in Figure 33 (B), all provinces show a positive and significant trend regarding electricity consumption. Khuzestan and Tehran have the highest Sen's slope values, 846 and 808, respectively (see appendix 5). Meanwhile, Ardebil, Chaharmahal and Bakhtiari, Semnan, and Zanzan have the lowest Sen's slope values, recorded at 28, 18, 27, and 27, respectively.

CO<sub>2</sub> emissions have increased significantly in all provinces, except for Isfahan, which does not exhibit a significant trend. Among the provinces, Tehran, Khorasan, Mazandaran, and Western Azerbaijan have the highest Sen's slope values, with growth amounts of 456,905, 315,775, 306,495, and 297,754, respectively (see appendix 6). In contrast, Hormozgan and Sistan and Baluchestan have the lowest increases in Sen's slope, with values of 1,894 and 1,082, respectively.



**Figure 33.** Man-Kendall trend and Sen's slope distribution of oil use (A), gas use (B), electricity use (C) and CO<sub>2</sub> emissions (D), among provinces of Iran. (Created by the author)



**Figure 34.** Changes in % between 2001 and 2019 of Iran provinces for some energy variables: Percentage Change= (Value in 2022–Value in 2000/ Value in 2000)×100. (Created by the author)

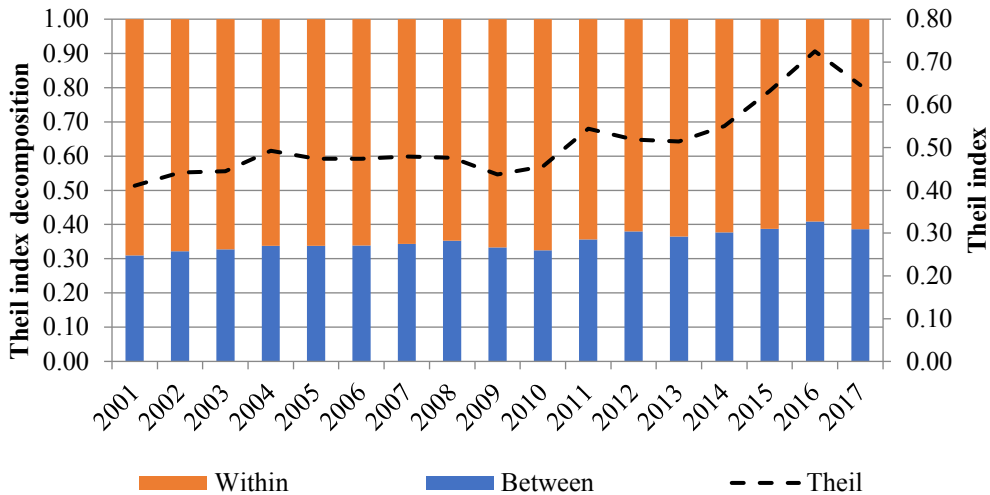
Figure 34 presents changes in CO<sub>2</sub> emissions and energy expenditure (oil, gas, and electricity) across the provinces of Iran from 2000 to 2019. The first graph illustrates changes in electricity usage, with the most significant fluctuations occurring in Kohgiluyeh, Khuzestan, Hormozgan, Bushehr, and Sistan and Baluchestan. In contrast, the provinces with the least change are Hamedan, Chaharmahal and Bakhtiari, and Ardebil. The second graph in Figure 31 shows changes in CO<sub>2</sub> emissions, revealing extreme variations in Ilam, Sistan and Baluchestan, Bushehr and Hormozgan. Conversely, the minimal changes are observed in the provinces of Tehran, Semnan, Qom, Golestan, Gilan, Hamedan, and Isfahan.

Gas usage demonstrates the most significant changes in Sistan and Baluchestan, Yazd, Western Azerbaijan, Hormozgan, Ilam, Bushehr, and Kermanshah. On the other hand, Semnan, Qom, Gilan, Golestan, and Tehran exhibit the lowest changes in gas consumption during the study period. The last graph depicts changes in oil consumption from 2001 to 2019 among the provinces of Iran. All provinces show

negative changes, except for Sistan and Baluchestan and Hormozgan, which still represent a significant amount of oil usage. These two provinces also exhibit substantial changes in CO<sub>2</sub> emissions during the study period.

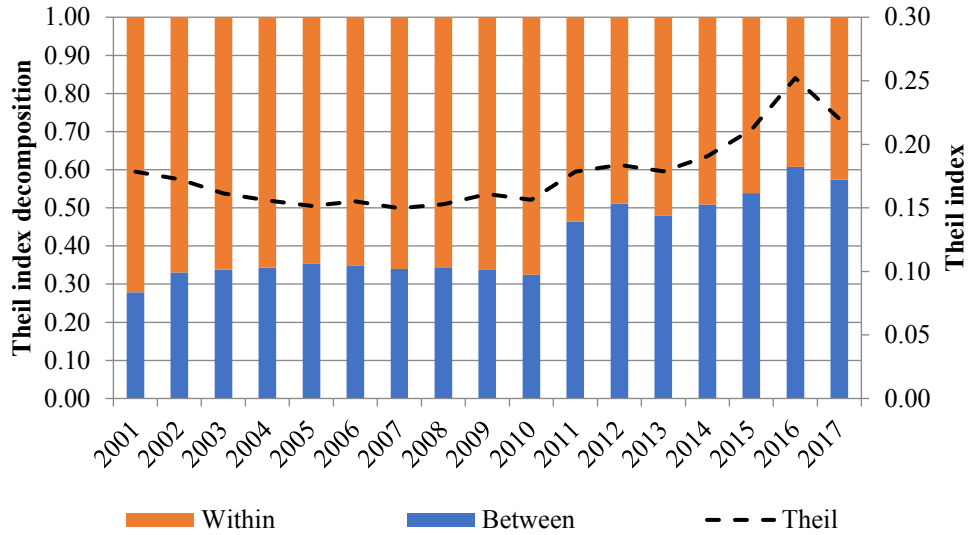
### **4.3. Analytic results**

The Theil index, which measures inequality across various energy sources containing natural gas, electricity and petroleum products, as well as CO<sub>2</sub> emissions, was calculated spending income and population data utilizing GDP classifications and regional income levels. This analysis considered both within-group and between-group disparities. As shown in the accompanying graphs, particularly Figure 35, the Theil index for oil products exhibited a notable upward trend, particularly from 2010 to 2016. In 2001, the index recorded a value of 0.40, which rose to 0.65 by 2017, indicating a rise in inequality. Furthermore, the level of inequality associated with petroleum energy sources was significant. Figure 35 indicates that within-group inequality accounted for approximately 70%, while between-group inequality made up about 30%. Following 2010, as household oil consumption declined, the level of inequality within groups increased. The initial phase of subsidies in 2010 contributed to rising inequality, which further escalated again in 2013. This was largely due to the second phase of subsidies initiated in 2013, particularly in the fuels sector, which significantly reduced the pay for power of low-wage households. However, after 2016, as the proportion of subsidies for household fuels decreased, inequality began to lessen. Most provinces experienced a downward trend in oil consumption, opting for gas as an alternative. However, certain regions, including Kerman and Sistan and Baluchestan, did not exhibit a reduction in oil use throughout the research timeframe, indicating a lack of access to gas supplies. This situation contributed to a rise in inequality concerning petroleum products.



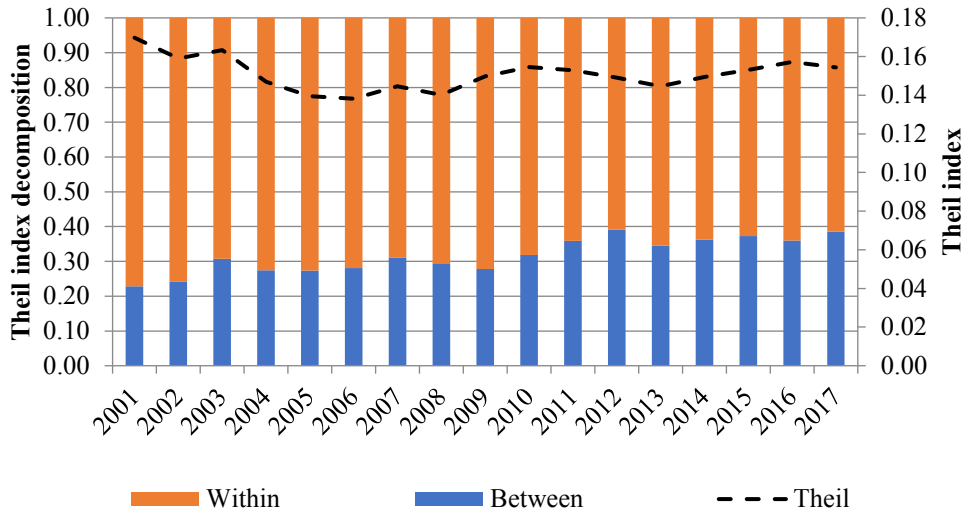
**Figure 35.** Income-weighted Theil Index for Petroleum Products. (Created by the author)

Figure 36 illustrates that the Theil index related to natural gas remained stable until 2010. Following that period, there was a noticeable increase in the index. Inequalities within and between groups were assessed based on GDP and geographical factors. This indicates that the groups formed using these criteria are quite diverse and lack commonalities. In fact, the majority of the inequality stems from the within-group component. Based on this analysis, it is essential to choose criteria that exhibit the highest level of heterogeneity among the groups. The most appropriate Theil index was selected using income groups and population weights. The Theil index measured 0.18 in 2001 and increased to 0.22 by 2017, with a peak of 0.25 in 2016. However, post-2016, there was a decrease in inequality due to a drop in the portion of subsidies for household fuels. Additionally, during the first decade, within-group inequality represented 72% of the total inequality, surpassing the levels of between-group inequality. This prevalence indicates disparities among provinces in terms of unit groups, primarily driven by entry to gas infrastructure. Regions such as Bushehr, Ilam, Sistan and Baluchestan and Hormozgan lacked gas access till 2010, and even after that, they only developed minimal gas infrastructure. Consequently, the shares between groups rose by 60% in 2017. The increase in gas consumption within groups 3 and 4, coupled with the subsidization phases in 2010 and 2013, significantly caused to the rise in inequality in the years following 2010.



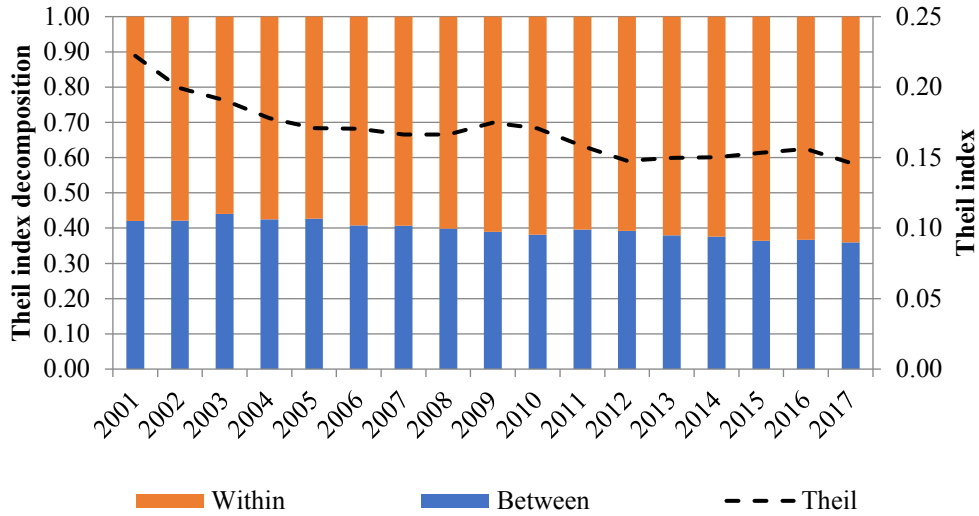
**Figure 36.** Population-weighted Theil Index for Natural Gas. (Created by the author)

Figure 37 illustrates the varying tendencies of the electricity Theil index over the evaluation period. Like other energy sources, within-group inequality was the most prominent. The Theil index was approximately 0.17 in 2001 and decreased to 0.15 by 2017, reflecting the fact that electricity access in the household sector was extended to all provinces during this time. Consequently, within-group inequality was greater than that of between-group inequality. Numerous factors caused the high levels of electricity consumption and persistent inequality. Firstly, per capita energy consumption was six times substantial than the global standard. Secondly, many households relied on outdated appliances that did not meet energy efficiency standards. Additionally, electricity prices, particularly during the summer months, were influenced by Iran's regional climate. Among the provinces, Khuzestan and Tehran exhibited the maximum electricity consumption; however, following the initial subsidy program, their consumption decreased. In contrast, during the second phase of the subsidy program, their expenditure increased. Overall, electricity in Iran is heavily subsidized (Barkhordar, 2019).



**Figure 37.** Population-weighted Theil Index for Electricity. (Created by the author)

Figure 38 illustrates a declining tendency in CO<sub>2</sub> emissions, adjusted for population weight, throughout the observation duration, suggesting a reduction in CO<sub>2</sub> production inequality within the household sector. Within-group inequality remained the most significant. This change can primarily be attributed to the decrease in oil consumption in households. The level of CO<sub>2</sub> production was 0.22 in 2001, declining to 0.14 by 2017, which still represents a substantial figure for the household sector. The high levels of CO<sub>2</sub> emissions are mainly due to the reliance on fossil fuels like gas, and secondly, because electricity for households is predominantly generated by oil power plants. Tehran recorded the highest CO<sub>2</sub> emissions and continued to see increases even after the implementation of the first subsidy program in 2010.



**Figure 38.** Population-weighted Theil Index for CO<sub>2</sub> emissions. (Created by the author)

Tables 6 and 7 present the inequalities, both between and within groups, of the Theil index calculated using income and population weight for various energy sources and CO<sub>2</sub> emissions. Table 6 highlights that within-group inequality is predominant across all energy types (oil, gas, and electricity) as well as CO<sub>2</sub> emissions. There is only a minor distinction among the between-group and within-group inequalities for CO<sub>2</sub> and gas. Table 7 indicates that within-group inequality is prominent for oil, gas, and CO<sub>2</sub> in both scenarios. In contrast, electricity exhibited significant discrepancies between the between-group and within-group measures, reaching approximately 80%. Among the four indices evaluated for each type of fuel, the selection of the best index was based on the highest level of intergroup heterogeneity. The graphical trends for CO<sub>2</sub> emissions and all energy sources reflect ongoing inequality. The Theil index for oil consumption was notably greater than that of additional fuels, indicating a significant level of inequality (over 0.5). While the inequality associated with other fuels and CO<sub>2</sub> emissions was not as pronounced, it exhibited an upward trend over the research interval. Regardless of implementing two phases of subsidy programs, one of Iran's development plans revealed that these initiatives were not effective and actually contributed to increased inequality in household consumption across provinces. Low-income families were particularly affected by these subsidy programs; the removal of subsidies pushed many of them below the poverty line. The government continues to allocate substantial subsidies for energy sources (oil, gas, and electricity). For instance, in 2013, the cost of electricity production was approximately 1300 Rial per kW, yet households only paid around 430 Rial (0.0134 dollars).

**Table 6.** Disparity of the Theil Index using population weight for various grouping methods, both between (B) and within (W) groups. (Created by the author)

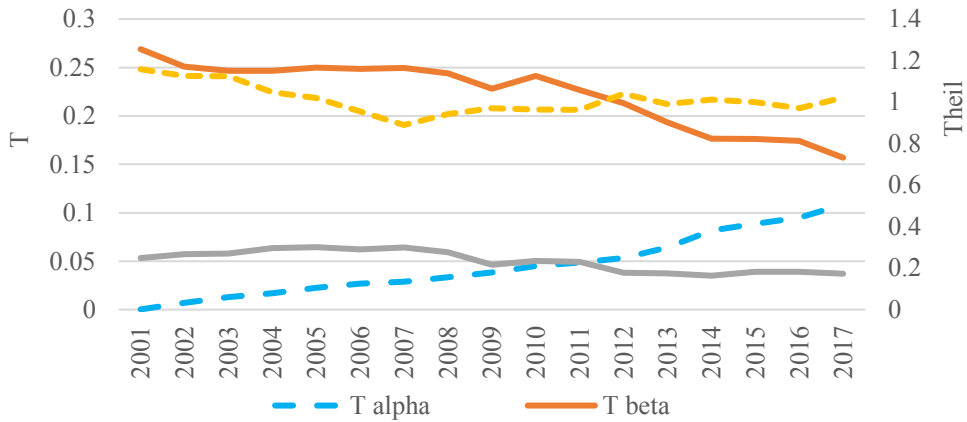
<b>Grouping Methodology</b>	<b>Variable</b>	<b>B W</b>	<b>2001</b>	<b>2002</b>	<b>2003</b>	<b>2004</b>	<b>2005</b>	<b>2006</b>	<b>2007</b>	<b>2008</b>	<b>2009</b>
GDP	Oil products	B	26.34	27.05	28.46	30.59	28.18	28.08	28.80	29.86	28.81
		W	73.66	72.95	71.54	69.41	71.82	71.92	71.20	70.14	71.19
	Natural 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 <sub>2</sub> 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 <sub>2</sub> 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
<b>Grouping Methodology</b>	<b>Variable</b>	<b>B W</b>	<b>2010</b>	<b>2011</b>	<b>2012</b>	<b>2013</b>	<b>2014</b>	<b>2015</b>	<b>2016</b>	<b>2017</b>	
GDP	Oil products	B	29.47	38.70	38.66	36.47	37.79	37.49	38.85	37.88	
		W	70.53	61.30	61.34	63.53	62.21	62.51	61.15	62.12	
	Natural gas	B	32.43	46.40	51.06	48.01	50.84	53.85	60.77	57.42	
		W	67.57	53.60	48.94	51.99	49.16	46.15	39.23	42.58	
	Electricity	B	24.74	25.69	25.75	24.86	25.27	25.27	25.10	25.30	
		W	75.26	74.31	74.25	75.14	74.73	74.73	74.90	74.70	
	CO <sub>2</sub> emissions	B	38.08	39.56	39.17	37.94	37.58	36.39	36.68	35.93	
		W	61.92	60.44	60.83	62.06	62.42	63.61	63.32	64.07	
Population	Oil products	B	29.97	39.12	38.29	36.39	36.10	34.70	36.38	35.48	
		W	70.03	60.88	61.71	63.61	63.90	65.30	63.62	64.52	
	Natural gas	B	38.18	39.00	39.00	37.53	37.24	36.79	36.31	35.69	
		W	61.82	61.00	61.00	62.47	62.76	63.21	63.69	64.31	
	Electricity	B	31.85	35.91	39.13	34.53	36.26	37.24	35.95	38.57	
		W	68.15	64.09	60.87	65.47	63.74	62.76	64.05	61.43	
	CO <sub>2</sub> emissions	B	38.14	38.96	38.96	37.49	37.21	36.76	36.28	35.65	
		W	61.86	61.04	61.04	62.51	62.79	63.24	63.72	64.35	

**Table 7.** Disparity of the Theil index according to income weight for various grouping methodologies between (B) and within (W) groups. (Created by the author)

<b>Grouping Methodology</b>	<b>Variable</b>	<b>B W</b>	<b>2001</b>	<b>2002</b>	<b>2003</b>	<b>2004</b>	<b>2005</b>	<b>2006</b>	<b>2007</b>	<b>2008</b>	<b>2009</b>
GDP	Oil products	B	30.94	32.14	32.72	33.78	33.73	33.88	34.37	35.26	33.27
		W	69.06	67.86	67.28	66.22	66.27	66.12	65.63	64.74	66.73
	Natural gas	B	28.87	28.32	28.51	28.36	29.22	28.25	28.52	26.25	23.10
		W	71.13	71.68	71.49	71.64	70.78	71.75	71.48	73.75	76.90
	Electricity	B	13.84	14.04	12.06	11.87	14.40	15.24	16.45	14.14	10.17
		W	14.04	85.96	87.94	88.13	85.60	84.76	83.55	85.86	89.83
	CO <sub>2</sub> emissions	B	28.84	28.30	28.48	28.33	29.19	28.23	28.50	26.22	23.08
		W	71.16	71.70	71.52	71.67	70.81	71.77	71.50	73.78	76.92
Population	Oil products	B	28.71	30.06	31.00	32.09	32.22	32.24	32.05	32.31	30.74
		W	71.29	69.94	69.00	67.91	67.78	67.76	67.95	67.69	69.26
	Natural gas	B	27.30	26.96	27.74	27.58	28.59	27.49	27.85	25.42	22.62
		W	72.70	73.04	72.26	72.42	71.41	72.51	72.15	74.58	77.38
	Electricity	B	6.05	6.47	5.78	5.85	7.68	7.97	8.95	6.58	6.55
		W	93.95	93.53	94.22	94.15	92.32	92.03	91.05	93.42	93.45
	CO <sub>2</sub> emissions	B	47.46	45.25	44.39	44.20	45.39	43.88	43.05	43.19	30.02
		W	52.54	54.75	55.61	55.80	54.61	56.12	56.95	56.81	69.98
<b>Grouping Methodology</b>	<b>Variable</b>	<b>B W</b>	<b>2010</b>	<b>2011</b>	<b>2012</b>	<b>2013</b>	<b>2014</b>	<b>2015</b>	<b>2016</b>	<b>2017</b>	
GDP	Oil products	B	32.42	35.67	38.01	36.49	37.70	38.78	40.88	38.64	
		W	67.58	64.33	61.99	63.51	62.30	61.22	59.12	61.36	
	Natural gas	B	25.50	26.48	22.63	24.05	23.17	23.68	24.36	23.55	
		W	74.50	73.52	77.37	75.95	76.83	76.32	75.64	76.45	
	Electricity	B	9.76	10.43	8.76	6.18	7.94	8.96	9.05	10.05	
		W	90.24	89.57	91.24	93.82	92.06	91.04	90.95	89.95	
	CO <sub>2</sub> emissions	B	25.47	26.46	22.60	24.03	23.14	23.66	24.34	23.53	
		W	74.53	73.54	77.40	75.97	76.86	76.34	75.66	76.47	
Population	Oil products	B	29.88	33.18	34.68	33.66	33.24	33.95	35.93	34.72	
		W	70.12	66.82	65.32	66.34	66.76	66.05	64.07	65.28	
	Natural gas	B	24.93	25.67	21.56	22.72	21.81	22.51	23.21	22.30	
		W	75.07	74.33	78.44	77.28	78.19	77.49	76.79	77.70	
	Electricity	B	5.70	5.91	5.70	3.83	5.59	6.22	6.22	7.22	
		W	94.30	94.09	94.30	96.17	94.41	93.78	93.78	92.78	
	CO <sub>2</sub> emissions	B	36.38	37.79	29.03	29.36	26.81	28.21	28.84	27.42	
		W	63.62	62.21	70.97	70.64	73.19	71.79	71.16	72.58	

### 4.3.1. Kaya factor

To investigate the factors contributing to the disparity in CO<sub>2</sub> emissions within the household sector, the Kaya identity was utilized, and Theil indexes were recalculated based on the Kaya components. The trends associated with the Kaya identity are illustrated in Figure 39 and Table 8. The Theil index showed a gradual decline until 2007, followed by a slight uptick due to an increase in gas consumption in place of oil in households. However, the primary factor contributing to the rise in disparity of CO<sub>2</sub> emissions was the T beta (energy efficiency factor), indicating that energy efficiency has played a significant role in driving this inequality. The main factor contributing to the inequality is the inefficient performance of appliances and technology utilized in households. These devices are primarily used for cooling, cooking, water heating, heating, lighting, and essential electricity needs. Energy inefficiency in Iran can be attributed to two main reasons: first, there is a growing number of appliances, including irons, washing machines, electric heaters, gas water heaters and gas heaters. Second, the prevalence of outdated and non-standard appliances contributes to higher energy consumption, compounded by the relatively low usage of efficient LED lighting in households. Additionally, specific provinces, such as Bushehr, Sistan and Baluchestan, lack access to gas, leading to a preference for oil heaters, which in turn raises CO<sub>2</sub> emissions and results in greater energy inefficiency. Despite this, energy efficiency remains the primary driver of CO<sub>2</sub> disparity in the household sector. If this tendency persists, CO<sub>2</sub> emissions will continue to boost fossil fuel expenditure. The materials used in building construction and the household appliances are often neither suitable nor efficient. Furthermore, T alpha has shown an upward trajectory, particularly following 2010 and the initial subsidy program, making T Alpha (fossil fuels) a key contributor to inequality. As shown in Table 8, the positive correlation among CO<sub>2</sub> intensity and energy expenditure outweighs the relationship between energy intensity and GDP, suggesting that the rise in CO<sub>2</sub> emissions is closely tied to enhanced energy inefficiency.



**Figure 39.** Analysis of CO<sub>2</sub> emissions through the lens of Kaya factors. (Created by the author)

**Table 8.** Analysis of CO<sub>2</sub> emissions in Iran's household sector using Kaya factors and their interactions. (Created by the author)

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

#### 4.4. Econometric results

Table 9 presents a statistical overview of the variables analyzed in their natural logarithmic form. A balanced panel dataset comprising 532 observations was created, covering 28 provinces from 2001 to 2019. The statistical mean assesses the central tendency of the variable distributions, while variance and standard deviation are stated to illustrate their variation. The findings indicate that most variables exhibited low standard deviation values, suggesting minimal dispersion among them. Additionally, the maximum and minimum values for each variable are provided. Skewness and kurtosis were calculated to evaluate the distribution characteristics of the data. The majority of the distributions exhibit moderate skewness and lighter tails when compared to a normal distribution. The final column displays the indicators of the normality status for the variables, showing that all variables significantly reject the null hypothesis in the Shapiro-Wilk normality test. It is important to mention that the chosen estimation methods do not necessitate data that is normally distributed.

**Table 9.** Statistical overview of the variables under investigation. (Created by the author)

Variable	OBS	Mean	Std. Dev.	Max	Min	Skewness	Kurtosis	Variance	Shapiro-Wilk
Log c	532	14.3	2.12	17.5	6.73	-1.9	6.73	4.5	10.55***
Log t1	532	2.80	0.24	8.45	3.89	0.05	3	0.05	11.04***
Log t2	532	5.10	1.60	7.70	-0.59	-0.84	3.35	2.56	7.39***
Log pr	532	5.50	0.77	7.73	2.63	-0.44	3.83	0.60	4.98***
Log oil	532	12.09	1.05	14.6	8.30	-0.29	3.06	1.11	2.49***
Log gas	532	6.60	1.64	9.75	0	-1.62	6.76	2.70	9.52***
Log elec	532	7.54	0.96	10.3	5.50	0.60	2.95	0.92	5.93***
Log op	532	6.95	0.43	7.57	6	-0.73	2.67	0.18	7.28***
Log gp	532	6.58	0.67	7.57	5.30	-0.05	1.73	0.45	7.60***
Log ep	532	6.22	0.21	6.49	5.76	-0.88	2.84	0.04	8.87***
Log i	532	19.26	0.92	22.6	17.41	0.90	3.71	0.86	7.08***
Log s	532	1.34	0.15	1.91	1.02	0.71	3.20	0.02	6.21***
Log e	532	4.42	0.05	4.53	4.15	-1.40	7.77	0.002	8.32***
Log em	532	3.23	0.23	3.77	1.85	-1.56	8.16	0.05	8.50***

Log b	532	8.35	0.76	10.6	6.91	0.64	2.69	0.58	6.68***
Log u	532	4.17	0.18	4.56	3.75	0.20	2.51	0.03	4.26***
d	532	0.52	0.49	1	0	-0.10	1.01	0.25	-

Note: \* refers to 10%, \*\* is 5%, and \*\*\* is 1% significance level.

#### 4.4.1. Cross-sectional dependence result

The findings from the Pesaran CD test for cross-sectional independence are summarized in Table 10 below. The outcomes indicate a strong rejection of the null hypothesis for all variables, suggesting that the standard errors in the subsequent estimates are biased. To address this issue, applying Driscoll and Kraay standard errors in estimations, along with the FGLS method, are widely recognized strategies (Dehdar et al., 2022; Muzayanah et al., 2022).

**Table 10.** Findings on cross-sectional dependence. (Created by the author)

Variable	CD-test	P-Value	Correlation
Log c	70.60***	0.00	0.83
Log t1	44.53***	0.00	0.52
Log t2	11.94***	0.00	0.14
Log pr	31.54***	0.00	0.37
Log oil	62.94***	0.00	0.74
Log gas	76.24***	0.00	0.93
Log elec	80.67***	0.00	0.95
Log op	84.75***	0.00	1.00
Log gp	84.75***	0.00	1.00
Log ep	84.75***	0.00	1.00
Log i	75.61***	0.00	0.89
Log s	83.80***	0.00	0.98
Log e	83.37***	0.00	0.98
Log em	30.12***	0.00	0.35
Log b	53.00***	0.00	0.62
Log u	68.61***	0.00	0.81
d	84.75***	0.00	1.00

Note: \* refers to 10%, \*\* is 5%, and \*\*\* is 1% significance level.

#### 4.4.2. Multicollinearity result

In reference to the multicollinearity assessment presented in Table 11, entirely distinct variance inflation factor (VIF) principles are significantly below the commonly acknowledged limit of 10, indicating that multicollinearity is not present amid the independent variables. Additionally, the average VIF is also below 10, suggesting that multicollinearity does not affect our models. Consequently, research able to rely on the accuracy of the expected coefficients and figure out the models with confidence.

**Table 11.** Variance Inflation Factor (VIF) values for the variables (Created by the author)

Variables	VIF	1/VIF	Mean VIF
Log t1	6.50	0.15	5.03
Log t2	2.66	0.37	
Log pr	1.57	0.63	
Log oil	3.95	0.25	
Log gas	6.52	0.15	
Log elec	1.49	0.67	
Log op	5.90	0.17	
Log gp	6.84	0.14	
Log ep	9.73	0.10	
Log i	7.67	0.13	
Log s	9.80	0.10	
Log e	4.65	0.21	
Log em	1.74	0.57	
Log b	4.13	0.24	
Log u	2.59	0.38	
d	4.78	0.20	

#### 4.4.3. Results of the panel unit root test

We employed the Cross-Sectional Augmented Dickey-Fuller panel unit-root test, introduced by (Pesaran, 2007), to examine the stationarity of all the variables. The results, displayed in Table 12, present findings in two formats: with trends and without trends. From the outcomes, it is clear that all variables, aside from precipitation levels, electricity and gas expenditure, and household income, are nonstationary when trends are not considered. However, once a tendency is incorporated, we observe altered results of CO<sub>2</sub> emissions, precipitation levels, electricity and gas expenditure, and building stock are stationary at their original levels, while the other variables remain nonstationary. Following the first

differentiation, all nonstationary variables achieved stationarity at a significance level of 1%, as indicated in the last column.

**Table 12.** Results of the CADF unit root test. (Created by the author)

Variable	Lags	Without Trend		With Trend		Result
		Z [t-bar]	P-value	Z [t-bar]	P-value	
Log c	1	2.28	0.98	-1.85**	0.03	I(0)
Log t1	1	4.53	1.00	2.96	0.99	I(1)
Log t2	1	0.45	0.67	-0.83	0.20	I(1)
Log pr	1	-3.64***	0.00	-1.91**	0.02	I(0)
Log oil	1	-0.92	0.17	0.24	0.60	I(1)
Log gas	1	-2.35***	0.00	4.01***	0.00	I(0)
Log elec	1	-3.33***	0.00	-2.61***	0.00	I(0)
Log op	1	22.56	1.00	20.90	1.00	I(1)
Log gp	1	22.56	1.00	20.90	1.00	I(1)
Log ep	1	22.56	1.00	20.90	1.00	I(1)
Log i	1	-3.93***	0.00	-0.83	0.20	I(0)
Log s	1	1.85	0.96	1.78	0.196	I(1)
Log e	1	3.25	0.99	3.63	1.00	I(1)
Log em	1	-0.29	0.38	-1.17	0.12	I(1)
Log b	1	-3.78***	0.00	-1.40*	0.08	I(0)
Log u	1	10.70	1.00	9.12	1.00	I(1)

Note: \* refers to 10%, \*\* is 5%, and \*\*\* is 1% significance level.

#### 4.4.4. Panel co-integration result

Once certain variables are nonstationary, it is essential to determine whether they are co-integrated. To achieve this, we utilized the Kao co-integration test to further examine the relationship between the dependent and independent variables. The findings presented in Table 13 indicate that entirety five versions of the Kao co-integration test decisively rejected the null hypothesis of no co-integration. The existence of co-integration suggests that the estimation results are not superior and that there is a long-term correlation among the variables.

**Table 13.** Results of the Kao cointegration test. (Created by the author)

Modified Fuller t		Dickey-Fuller t		Augmented Fuller t		Unadjusted Modified Dickey-Fuller t		Unadjusted Dickey-Fuller t	
Statistic	P-Value	Statistic	P-Value	Statistic	P-Value	Statistic	P-Value	Statistic	P-Value
-6.31***	0.00	-12.6***	0.00	-7.44***	0.00	-15.8***	0.00	-15.9***	0.00

Note: \* refers to 10%, \*\* is 5%, and \*\*\* is 1% significance level.

#### 4.4.5. Static estimation

We assessed the effects of energy consumption, climate conditions, and household socio-economic factors on CO<sub>2</sub> emissions using various panel data regression techniques. To begin, we conducted the Hausman test. The results presented in Table 14 show a strong rejection of the null hypothesis, indicating that the Fixed Effect (FE) model is a reliable choice for our estimations. Next, we performed an F-test to determine the most suitable model among the FE and PLS approaches. The test indicates a statistically significant result at the 1% level, leading to the selection of the Fixed Effect (FE) model for further analysis (refer to Table 19). Additionally, we utilized the Wooldridge test to assess for autocorrelation. According to the results shown in Table 14, the null hypothesis was firmly rejected, suggesting that there is indeed an issue with autocorrelation in the estimated FE model. Subsequently, the Wald test is conducted to assess group-wise heteroscedasticity within the model. According to the findings of the Wald test presented in Table 14, a heteroscedasticity issue is identified in the estimated Fixed Effect (FE) model. Additionally, we perform the Pesaran cross-sectional dependence test to investigate the correlation among panel units. The results in Table 14 lead to the rejection of the null hypothesis, confirming the presence of cross-sectional dependence in the estimated model. Considering the outcomes of the tests in Table 14, it appears that the estimation results of the FE model may be misleading and biased. To address these challenges, we employed the FGLS estimation method, which provides reliable and accurate results (see Table 15 below).

**Table 14.** Model selection tests. (Created by the author)

Tests	Statistics	P-Value
Hausman (Between FE and RE)	252.91***	0.00
F-Limer (Between FE and PLS)	18.21***	0.00
Autocorrelation (Wooldridge)	47.26***	0.00
Heteroscedasticity (Wald)	38.29*	0.09
Weak Cross-Sectional dependence (Pesaran)	54.57***	0.00
Final Model	FGLS	

Note: \* refers to 10%, \*\* is 5%, and \*\*\* is 1% significance level.

The findings from the FGLS estimation, presented in Table 15, indicate that all variables are statistically significant at both the 1% and 5% levels, except for electricity price. The results suggest that household CO<sub>2</sub> emissions are positively correlated with factors such as heating degree days (HDD), cooling degree days (CDD), levels of precipitation, consumption of oil and gas, household income, household size, and the stock of buildings. This means that as these factors increase, so do household CO<sub>2</sub> emissions.

In contrast, electricity consumption, prices of oil and gas, the rate of education, employment rates in households, the rate of urbanization, and a dummy variable show a negative association with emissions, implying that as these factors rise, household CO<sub>2</sub> emissions tend to decrease. To elaborate, the educational rate, the dummy variable, and oil price have the most pronounced negative effects on emissions, with elasticities of -0.428, -0.31, and -0.15, respectively. On the other hand, household size, along with gas and oil consumption, exhibits the strongest positive influence on CO<sub>2</sub> emissions, with elasticities of 0.1, 0.044, and 0.026, respectively. When it comes to climate-related factors, a 1% increase in Heating Degree Days (HDD), Cooling Degree Days (CDD), and precipitation levels directs to increases in CO<sub>2</sub> emissions of 0.024%, 0.004%, and 0.011%, respectively. In terms of energy factors, our analysis shows that provinces with higher oil and gas consumption, such as Mazandaran, Isfahan, Tehran, West Azerbaijan, East Azerbaijan and Khorasan, generate greater CO<sub>2</sub> emissions.

Specifically, a 1% rise in oil and gas expenditure results in increases of 0.026% and 0.044% in CO<sub>2</sub> emissions. The coefficient for electricity expenditure is negative, indicating that a 1% rise in electricity expenditure results in a reduction in CO<sub>2</sub> emissions. As anticipated, a 1% increase in energy prices for oil and gas leads to a desirable decrease in CO<sub>2</sub> emissions. The dummy variable representing the elimination of energy subsidies indicated a negative impact on CO<sub>2</sub> emissions in the

western provinces throughout the study period. We observed similar findings concerning the effect of energy prices on emissions. This suggests that increasing energy prices is beneficial for the environment. Six social and economic factors from the estimated model household size, building stock, household income, employment status, urbanization rate and education level have both positive and negative effects on CO<sub>2</sub> emissions. This suggests that in the provinces of Iran, an increase in household income and the number of household members is associated with higher CO<sub>2</sub> emissions. In other words, Households are likely to raise CO<sub>2</sub> emissions due to various factors, such as increased energy consumption linked to higher income levels (a variation of the Environmental Kuznets Curve theory). For each additional person in a household, CO<sub>2</sub> emissions are expected to rise by 0.11%. Additionally, a 1% increase in education and employment rates is associated with decreases in CO<sub>2</sub> emissions of 0.428% and 0.022%, respectively. A decrease of 0.067 in CO<sub>2</sub> emissions is a result of an expansion of 1% in urbanity. Although we anticipated a negative effect from building stock, the findings indicate that an increase in the number of buildings corresponds to higher CO<sub>2</sub> emissions, with an elasticity of 0.014. This means that energy consumption related to building operations in Iran's provinces contributes significantly to environmental degradation.

**Table 15.** Results of the FGLS estimation. (Created by the author)

<b>Variables</b>	<b>Coefficients</b>	<b>Std. Dev.</b>	<b>P-value</b>
Log t1	0.024 <sup>***</sup>	0.007	0.00
Log t2	0.004 <sup>**</sup>	0.002	0.03
Log pr	0.011 <sup>***</sup>	0.003	0.00
Log oil	0.026 <sup>***</sup>	0.004	0.00
Log gas	0.044 <sup>***</sup>	0.003	0.00
Log elec	-0.09 <sup>***</sup>	0.012	0.00
Log op	-0.15 <sup>***</sup>	0.026	0.00
Log gp	-0.026 <sup>**</sup>	0.013	0.04
Log ep	-0.038	0.030	0.20
Log i	0.011 <sup>**</sup>	0.006	0.05
Log s	0.11 <sup>***</sup>	0.015	0.00
Log e	-0.428 <sup>***</sup>	0.030	0.00
Log em	-0.022 <sup>**</sup>	0.011	0.05
Log b	0.014 <sup>***</sup>	0.005	0.00
Log u	-0.067 <sup>***</sup>	0.019	0.00
d	-0.31 <sup>***</sup>	0.022	0.00
Wald Test	4.46×10 <sup>7</sup> <sup>***</sup>		0.00

Note: \* refers to 10%, \*\* is 5%, and \*\*\* is 1% significance level.

#### 4.4.6. Dynamic estimation

Table 16 presents the results of the Hausman test, which helps determine whether to use the system GMM or the difference GMM estimators. The null hypothesis posits that the difference GMM is the preferred model, while the alternative hypothesis supports the system GMM. The results indicate a strong rejection of the null hypothesis, leading to the choice of system GMM for beyond analysis. It is important to note that the results from the difference GMM estimator are similar to those from the system GMM estimator, suggesting that the estimated models are robust across different dynamic approaches.

**Table 16.** Hausman test for choosing a model. (Created by the author)

Test	Result
Hausman test (Between Difference and System GMM)	2626.6***

Note: \* refers to 10%, \*\* is 5%, and \*\*\* is 1% significance level. (Created by author)

The results from the system GMM estimator are shown in Table 17 and align closely with the findings from the previous section. The Sargan test results indicate that the null hypothesis is not rejected, confirming that the instruments are valid and uncorrelated with the error terms. Additionally, the null hypothesis of the Arellano-Bond tests is also not rejected, suggesting there is no autocorrelation issue in the estimated model. The analysis reveals that all independent variables, except for household size and urbanization, are statistically significant at least at the 10% level. Among the estimated variables, Heating Degree Days (HDD), Cooling Degree Days (CDD), precipitation levels, oil and gas consumption, household income, building stock, and the dummy variable have a positive impact on CO<sub>2</sub> emissions from households. Conversely, the coefficients for energy prices, education rate, employment rate, and the dummy variable are negative, indicating that these variables reduce household CO<sub>2</sub> emissions. The educational rate has the most significant negative impact, while gas consumption shows the highest positive effect, with elasticities of -0.38 and 0.89, respectively. This highlights the substantial influence of both social and energy factors on household carbon emissions.

Regarding energy factors, a 1% rise in oil and gas expenditure results in an increase in CO<sub>2</sub> emissions of 0.023% and 0.89%, respectively. On the other hand, electricity consumption demonstrates an opposing effect; specifically, a 1% increase in electricity use corresponds to a decrease of 0.07% in CO<sub>2</sub> emissions. With respect to energy prices, our findings indicate that a 1% increase in the prices of oil, gas, and

electricity results in reductions in CO<sub>2</sub> emissions of 0.10%, 0.074%, and 0.15%, respectively. The information presented here shows that increasing energy prices does not lead to a decrease in CO<sub>2</sub> emissions. As anticipated, the dummy variable indicates a significant negative effect on emissions. This suggests that eliminating energy subsidies or implementing a re-pricing policy could effectively help manage carbon emissions from households in various provinces of the country, including Tehran, Khorasan, and Mazandaran.

Household income, as an economic variable, shows a moderate positive elasticity, indicating that CO<sub>2</sub> emissions rise as household income increases. Specifically, a 1% increase in income corresponds to an approximate increase of 0.045% in emissions. In contrast, the employment and education rates of households demonstrate significant negative effects on emissions, suggesting that these social factors are vital in influencing household CO<sub>2</sub> emissions, with elasticities of -0.38 and -0.064, respectively. Moreover, activities related to building operations in the provinces of Iran contribute to rising household CO<sub>2</sub> emissions, with a 1% increase in building stock leading to an increase of 0.019% in CO<sub>2</sub> emissions.

**Table 17.** System GMM results

Variables	Coefficients	Std. Dev.	P-value
l.Log c	0.046***	0.019	0.00
Log t1	0.038***	0.008	0.00
Log t2	0.007***	0.002	0.00
Log pr	0.015***	0.003	0.00
Log oil	0.023***	0.006	0.00
Log gas	0.89***	0.016	0.00
Log elec.	-0.07***	0.016	0.78
Log op	-0.10***	0.030	0.00
Log gp	-0.074***	0.006	0.00
Log ep	-0.15***	0.032	0.00
Log i	0.049***	0.006	0.00
Log s	0.17	0.14	0.21
Log e	-0.38***	0.19	0.00
Log em	-0.064**	0.033	0.05
Log b	0.019***	0.004	0.00
Log u	-0.38	0.44	0.38
d	-0.31***	0.04	0.00
Sargan Test	25.28		1.00
Bond Test AR(2)	1.00		0.31
Wald Test	5.62×10 <sup>6</sup> ***		0.00

Note: \* refers to 10%, \*\* is 5%, and \*\*\* is 1% significance level.

## 4.5. Discussion

A review of global scientific literature highlights that the major factors contributing to inequality include CO<sub>2</sub> emissions, economic fluctuations, and income variations (Bianco et al., 2019a; L. Chen et al., 2019a; Padilla & Serrano, 2006a; Remuzgo & Sarabia, 2015b; Y. Wang & Zhao, 2018). The present research findings indicate that economic changes and the subsidy program have significantly contributed to increased inequality. Additionally, varying income levels among the provinces in Iran serve as another major source of disparity. Consequently, provinces with lower income levels face greater challenges in energy consumption due to insufficient infrastructure.

The analysis examined the disparities in gas, electricity and oil expenditure, as well as CO<sub>2</sub> emissions, in the household sector of Iran's provinces from 2001 to 2017. There are other similar research efforts in Iran that could provide valuable insights into the issues of inequality or the rise in equality. According to research by Hafeznia et al (2017), it was noted that Iran's natural gas sector is challenged by rising domestic demand, considerable energy losses in residential and commercial areas, and low efficiency in the industrial and power generation sectors. If these obstacles can be addressed, natural gas could serve as a pathway for Iran's shift towards a low-carbon future. The current analysis demonstrated that during the period when the country transitioned from oil to gas consumption, there was a significant reduction in CO<sub>2</sub> emissions from the household sector. Which our trend analysis represented shifting from oil to gas use particularly after 2010.

Nonetheless, Barkhordar (2019) showed that LED lamps provided by governments can reduce energy consumption and enhance energy efficiency for households. Since the current investigation identified energy efficiency as a factor contributing to the rise in CO<sub>2</sub> emissions, this recommendation could lead to improved efficiency and lower energy consumption and CO<sub>2</sub> emissions. In addition, Hajilary et al (2018) concluded that energy consumption and expenses, population density, non-oil GDP, and foreign direct investment (FDI) significantly influence CO<sub>2</sub> emissions, with a linear relationship existing between these factors and emissions. The present research proves some part of that research regarding energy consumption and relationship with CO<sub>2</sub> emissions. Moreover, Moshiri (2015) concluded that the removal of energy subsidies in Iran was a crucial aspect of the energy pricing reform and vital for curbing the country's increasing energy consumption. The well-structured cash transfer system played a significant role in implementing the reform and gaining public support. However, to achieve energy efficiency targets, the changes must extend beyond just cutting subsidies. While

higher energy prices may encourage energy efficiency to some degree, the necessary capital investments and behavioural adjustments mean that these efficiency improvements will take time to develop. Additionally, energy prices need to remain elevated for an extended period to fully realize the benefits of energy efficiency; this means focusing on real energy prices rather than just nominal ones, with nominal prices set as a target.

The present analysis found that the energy price reform program was insufficient in managing energy consumption and CO<sub>2</sub> emissions. Based on the findings from Kaya and Theil, energy emerges as a critical factor that can significantly influence inequality in CO<sub>2</sub> emissions. Inequality within and between provinces has been influenced by government interventions in energy subsidies. It is clear that a uniform subsidy program has led to increased energy consumption, particularly of oil and natural gas. In contrast, the trends for electricity consumption and carbon emissions had been less stable, indicating that these factors were not impacted to the same extent as oil and natural gas. One of the key findings of this research was the assessment of inequality in energy consumption and CO<sub>2</sub> emissions in the household sector across Iran's provinces, taking into account population and income levels which level of analysis that has not been addressed in prior studies. Furthermore, the factors contributing to inequality like limited access to energy infrastructure and energy efficiency can provide valuable insights for policymakers when shaping regional energy policies in the future.

The result of trend analysis in regard of different fuels consumption and CO<sub>2</sub> emissions in residential sector of Iran represent, first of all, oil use in Sistan and Baluchestan and Hormozgan are the only provinces with a positive trend, showing a Sen's slope value of 12,312, 1557.9091 respectively. Most of provinces showed reduction in oil use which is in line with Nejat et al (2015) oil production has significantly decreased in Iran. Tehran solely with Sen's slope -129504, recorded a tremendous decrease. With Kendall's tau at -0.9883 ( $p < 0.0001$ ). In terms of gas usage, Tehran having the highest Sen's slope value at around 417. While some provinces exhibit a positive trend, the amounts are extremely low, including Sistan and Baluchestan, Hormozgan, Chaharmahal and Bakhtiari, Bushehr, and Ilam with Sen's slope 0.7214, 0.40, 23.6, 6.95, 19.12 respectively. all provinces show a positive and significant trend regarding electricity consumption. The results are same with Nejat et al (2015) electricity consumption also grew significantly in Iran. Khuzestan and Tehran have the highest Sen's slope values, 846 and 808, respectively. CO<sub>2</sub> emissions have increased significantly in all provinces the results of Nejat et al (2015) confirm our results which Iran has experienced the highest increase in CO<sub>2</sub> emissions over the past forty years. which is in line with Mirzaei and Bekri (2017) the overall CO<sub>2</sub> emissions showed an upward trend. except for Isfahan, which does not exhibit a

significant trend. Among the provinces, Tehran, Khorasan, Mazandaran, and Western Azerbaijan have the highest Sen's slope values. In contrast, Hormozgan and Sistan and Baluchestan have the lowest increases in Sen's slope, with values of 1,894 and 1,082, respectively.

According to second part of research, for the first time, current analysis examined the impact of 16 variables on residential sector CO<sub>2</sub> emissions in Iran at the regional level using both static and dynamic models, finding that most of the variables were significant. A notable aspect of present research yields specific findings regarding the regional context that have not been identified in earlier studies in Iran.

Specifically, in the static model, a 1% increase in oil and gas consumption leads to increases in CO<sub>2</sub> emissions of 0.026% and 0.044%, respectively like it was found by Fan et al (2019), Household carbon emissions are strongly influenced by both personal circumstances and household energy consumption and Hajilary et al (2019) findings revealed that energy consumption has a substantial impact on CO<sub>2</sub> emissions. Meanwhile, is contrary to Lotfalipour et al (2010) which shows no evidence was found of Granger causality between total fossil fuel consumption and carbon emissions in the long term. The dummy variable representing the hypothetical removal of energy subsidies demonstrated a negative impact on CO<sub>2</sub> emissions in the western provinces throughout the study period. The present analysis observed similar results concerning the effects of energy prices on emissions. This suggests that increased energy prices are beneficial for the environment. These latter results similar to the findings of Araghi and Barkhordari (2012) findings indicated that an increase in energy prices will lead to a reduction in energy consumption among Iranian households. Also, Farajzadeh and Nematollahi (2018) Given Iran's heavily subsidized energy system, removing energy subsidies could lead to a substantial decrease in energy intensity as prices rise.

In addition, Miao et al (2019) price elasticity is related to energy-related CO<sub>2</sub> emissions, meaning that higher energy prices will lead to a decrease in residential CO<sub>2</sub> emissions in China. Meanwhile is contrary to Hajilary et al (2018) it was shown that increasing energy prices does not lead to a decrease in energy consumption or a reduction in CO<sub>2</sub> emissions. Higher income and members of households in Iran's provinces, the higher the CO<sub>2</sub> emissions like Alajmi (2022) this study in Saudi Arabia found that the long-term elasticity of CO<sub>2</sub> emissions relative to GDP is positive and statistically significant, indicating that GDP has a substantial impact on carbon emissions. Also, Miao et al (2022) the key factor that positively influences total household CO<sub>2</sub> emissions is GDP per capita in China. Furthermore, Raza and Lin (2022) show that increased emissions are largely driven by economic activity in Pakistan. Meanwhile is contrary to Mohammed et al (2023) resulting in GDP growth

and a decrease in environmental pollution. An increase of one person in household size will cause an increase of 0.11 % in household CO<sub>2</sub> emissions. Also, 1% higher level of education and employment rate decrease CO<sub>2</sub> emissions by 0.428% and 0.022%, respectively which align with Meangbua et al (2019) the level of education of the head of household has a negative impact on the household's indirect energy consumption and associated CO<sub>2</sub> emissions.

A decrease of 0.067 in CO<sub>2</sub> emissions is a result of an increase of 1% in urbanity which differ than some researches like Bai et al (2019) an increasing proportion of the urban population has a substantial impact on residential CO<sub>2</sub> emissions. Also, Miao et al (2019) it is notable that urbanization is strongly positively linked to overall residential CO<sub>2</sub> emissions in numerous regions across China. Furthermore, Wang et al (2019) the influence of urbanization on household CO<sub>2</sub> emissions showed a rising trend moving from the southeastern coastal regions toward the northwest between 2000 and 2015. The results indicate that an increase in the number of buildings correlates with higher CO<sub>2</sub> emissions, exhibiting an elasticity of 0.014. In other words, energy consumption related to building operations across Iran's provinces contributes to environmental degradation. Among the climate factors, HDD shows the highest positive cause on CO<sub>2</sub> emissions the results are very alike to those of Sarak and Satman (2003) which indicate that the potential consumption in Türkiye in 2023 could be as high as 14.92 billion cubic meter (bcm) if 100% of the residents use natural gas for space heating.

Regarding dynamic models (system GMM), the results differ slightly from the static model in terms of magnitude and direction. In terms of energy factors, a 1% rise in oil consumption results in a 0.023% increase in CO<sub>2</sub> emissions, while the same increase in gas consumption leads to a 0.89% rise in emissions. in contrast with Wang and Zhao (2018) found that using more natural gas decreased household carbon emissions (HCE). Nevertheless, Electricity consumption has a different effect on emissions, with a 1% increase leading to a reduction of 0.07% in CO<sub>2</sub> emissions. In line with findings of Wang et al (2018) which increased electricity usage led to a reduction in HCE. In terms of energy prices, present findings which are same like static model indicate that a 1% increase in oil, gas, and electricity prices results in reductions of CO<sub>2</sub> emissions by 0.10%, 0.074%, and 0.15%, respectively. The dummy variable, shows a significant negative effect on emissions. This suggests that eliminating energy subsidies or implementing a re-pricing policy could be an effective method for managing carbon emissions from households in various provinces, including Tehran, Khorasan, and Mazandaran. Household income, as an economic factor, demonstrates a moderate positive elasticity, indicating that CO<sub>2</sub> emissions rise with increasing income. Specifically, a 1% increase in income corresponds to an approximate 0.045% rise in emissions. On the other hand, the

employment and education rates within households have a notable negative effect on emissions, suggesting that these social factors significantly influence household CO<sub>2</sub> emissions, with elasticities of -0.38 and -0.064, respectively. Furthermore, building operations in Iran's provinces contribute to rising household CO<sub>2</sub> emissions, as a 1% increase in building stock results in a 0.019% increase in emissions. Meanwhile in contrast with Balaras et al (2007) the increase in building stock, coupled with the implementation of energy conservation measures (ECMs) such as improved insulation and efficient heating systems, can significantly reduce CO<sub>2</sub> emissions in residential buildings. By enhancing energy efficiency and transitioning to renewable energy sources, the building sector can contribute to substantial reductions in greenhouse gas emissions while accommodating growing populations and urbanization. Also, Kamal et al (2019) the findings indicated that building energy-efficient structures and upgrading older ones every decade could save over 4,700 GWh of electricity and reduce CO<sub>2</sub> emissions by 2.3 million tons by 2050.

A significant gap in research on energy-related CO<sub>2</sub> emissions is the lack of focus on regional and spatial aspects. Many researchers, particularly engineers, tend to concentrate on technical energy issues while overlooking the importance of regional and spatial planning. This analysis represents the first comprehensive analysis at a regional level in Iran, making many of the findings novel and valuable for policymakers, government officials, and companies involved in renewable energy. More specifically, the descriptive and empirical analyses reveal that each variable affects the regions differently, with factors influencing the western provinces being distinct from those in the eastern provinces. In fact, even neighboring provinces can exhibit varying behaviors. The findings of this research provide a comprehensive overview for policymakers in Iran to mitigate household CO<sub>2</sub> emissions. Various factors, including climate, socio-economic conditions, energy fuels, and energy prices, were considered to understand regional disparities and develop effective policies. By analyzing household energy consumption and CO<sub>2</sub> emissions over the historical period at the provincial level, the analysis highlights the distinct circumstances of each province. This approach offers valuable insights into economic, climatic, societal, and fuel-mix factors, enabling tailored and effective energy policies. Low-income provinces such as Sistan and Baluchestan, Hormozgan, Ilam, and Bushehr face significant challenges. These regions have minimal access to natural gas and showed low consumption levels in 2019. Socio-economic indicators, such as low employment and education rates, limited urbanization, and large household sizes, further exacerbate household CO<sub>2</sub> emissions. In contrast, provinces like Tehran, Khorasan, Isfahan, Fars, and East Azerbaijan, with higher levels of urbanization, education, employment, and income, and smaller household sizes, tend

to emit less CO<sub>2</sub>. Provinces in the mid-range of socio-economic and energy factors exhibit moderate patterns regarding population and emissions.

To address these disparities, the Ministry of Energy, as the key authority in Iran's energy sector, must prioritize expanding energy infrastructure, particularly natural gas pipelines, in underserved regions. Additionally, they should implement income-based subsidies to reduce the energy cost burden on low-income households. These measures would directly tackle the vulnerabilities faced by economically disadvantaged provinces.

The Renewable Energy and Energy Efficiency Organization also plays a critical role. It should focus on improving energy efficiency by promoting standardized appliances, energy-efficient gas equipment, and renewable energy technologies in the household sector. Expanding the use of solar panels and other renewable energy sources, along with fostering private sector participation in renewable energy infrastructure development, can significantly contribute to reducing household CO<sub>2</sub> emissions.

The Department of Environment, tasked with monitoring CO<sub>2</sub> emissions across sectors, must strengthen regulations for energy-efficient construction. Implementing new standards for building materials and energy usage in the household sector is essential for long-term emission reduction. Furthermore, it is crucial to empower local governments and municipalities to implement policies tailored to their unique regional contexts. Local governments should also prioritize raising awareness about energy-saving practices among households and within the educational sector, promoting a culture of sustainability at the community level.

Iran's diverse ethnic, climatic, cultural, social, and economic conditions necessitate region-specific strategies. Identifying the factors influencing CO<sub>2</sub> emissions in each region and implementing targeted reforms are critical steps toward equitable energy policies. Aligning central and local planning will help reduce inequalities, mitigate household CO<sub>2</sub> emissions, and promote sustainable energy practices. These measures can pave the way for a more inclusive and environmentally conscious energy framework in Iran.

This investigation is innovative since it is the first to examine numerous variables, including temperature, socioeconomic circumstances, demographics, and energy use, at the province level in Iran over an extended period. The extensive analysis would determine the variables that affect CO<sub>2</sub> emissions and compare their respective effects, such as the relationship between socioeconomic characteristics and temperature. The current body of investigation focuses on regional and geographic variations. The study's findings can assist decision-makers in implementing regional CO<sub>2</sub> emission mitigation plans.

## 5. Summary and Conclusion

This study aimed to examine the disparities in oil, natural gas, and electricity consumption, as well as CO<sub>2</sub> emissions in the household sector across Iran's provinces from 2001 to 2017. The research identified various criteria for consumption inequality among the provinces and found that one significant factor contributing to this increase in inequality was the subsidy policies implemented in 2010 and 2013. Additionally, differences within and between various groups, such as GDP and population, also played a role. Furthermore, some provinces lacked access to gas and oil, which contributed to the disparities. Lastly, income inequality was evident, as provinces with lower income levels showed reduced consumption.

The Kaya identity analysis revealed that the primary factor contributing to the disparity in CO<sub>2</sub> emissions among Iran's provinces from 2001 to 2017 was energy efficiency. This indicates that many appliances and buildings did not incorporate standard materials. Additionally, the economic sector's structure played a significant role in the inequality, as there were no targeted programs for energy use across different sectors, and the subsidy initiatives did not maintain their initial effectiveness in addressing inequality among the population and the economy. Consequently, individuals with lower income levels fell deeper into poverty following the subsidies, as they were unable to access standard appliances and building materials.

Our research indicates that at the national level, subsidy implementation should be tailored to the specific circumstances of each province. The findings show that inequality among provinces grew during the period when subsidies were enacted. Many residents in various provinces of Iran still lack the resources and appliances that are commonly available in most advanced economies, with many individuals not having even basic access to modern energy. This highlights the need for more targeted efforts and a well-defined plan that takes into account the unique conditions of each province. Moreover, this research proposes several policies aimed at enhancing equality among provinces. First, there is a need for transitional energy subsidies to support renewable energy sources and promote clean energy in regions like Sistan, Hormozgan, and Bushehr, which suffer from inadequate energy infrastructure and electricity networks. Second, it is crucial to invest in energy efficiency, especially in major cities such as Tehran and Mashhad. Improving efficiency can be facilitated through transitional subsidies directed towards infrastructure and appliances.

The analysis utilized panel data and applied both static and dynamic methods to analyze the factors affecting CO<sub>2</sub> emissions across Iran's provinces from 2001 to 2019. The findings revealed that energy consumption, climate conditions, and socio-

economic factors significantly contribute to CO<sub>2</sub> emissions. Notably, energy consumption and climate variables (Heating Degree Days - HDD and Cooling Degree Days - CDD) had the most substantial impact on emissions. Specifically, provinces with larger populations and higher energy consumption, such as Tehran, Khorasan, Isfahan, and East Azerbaijan, emerged as the top emitters of CO<sub>2</sub>. The influence of temperature on CO<sub>2</sub> emissions varied across provinces. Regions such as Ardebil, East and West Azerbaijan, Zanjan, Hamedan, Ilam, and Chaharmahal and Bakhtiari, which exhibited the highest Heating Degree Days (HDD), recorded greater CO<sub>2</sub> emissions according to the findings. On the other hand, provinces like Khuzestan, Bushehr, Hormozgan, and Yazd, which had the highest Cooling Degree Days (CDD), required more electricity but produced lower CO<sub>2</sub> emissions.

Undoubtedly, Iran possesses significant fossil fuel resources and is among the top ten countries for CO<sub>2</sub> emissions. Thus, it is essential to undertake reforms across various sectors, especially in the household sector, which is a major contributor to CO<sub>2</sub> emissions. Reducing emissions in this area would facilitate a transition toward lower CO<sub>2</sub> outputs and less reliance on fossil fuels. Analyzing the different factors that influence CO<sub>2</sub> emissions in each region can provide valuable insights for the government and policymakers, enabling them to pinpoint key issues and develop targeted, region-specific strategies to optimize their investments.

One of the primary limitations of the investigation was the lack of access to detailed data at a smaller scale. Additionally, the significant disparities in development levels among provinces could lead to increased inequality. Future research should concentrate on assessing the development levels in each province and their connection to energy consumption. Furthermore, the pricing of energy and patterns of energy use are critical topics that deserve attention. Given Iran's substantial potential for renewable energy sources such as solar, wind, water, , and geothermal, along with the challenges posed by global warming, these areas should be prioritized in further research. Governments can encourage private sector investment in renewable energy for electricity generation. It is also crucial to engage local communities in adopting renewable energy solutions, like solar panels, especially in areas lacking electricity access.

A successful experience from the European Union (*Energy Performance of Buildings*, 2021) 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.

## 6. Acknowledgement

I would like to express my heartfelt gratitude to all those who contributed to the successful completion of this research. Their support, guidance, and encouragement played a crucial role throughout this journey.

I am particularly grateful to the Tempus Public Foundation for providing me with the opportunity to study and work while funding the essential aspects of this research. Their commitment to supporting students has made a significant impact on my academic journey.

A special thanks to my supervisor, Dr. János Péntzes, whose unwavering support and guidance were instrumental in shaping this work. His expertise, constructive feedback, and insightful discussions not only enhanced the quality of my research but also inspired me to push my boundaries. János's dedication to his students and his passion for the subject matter have left a lasting impression on me, and I am truly thankful for his mentorship throughout this process.

I would also like to express my deep appreciation for my colleagues, Dr. Parisa Pakrooh and Dr. Safwan Mohammed. Their collaboration and support were invaluable during the research process. Parisa's innovative ideas and critical insights helped refine my approach, while Safwan's encouragement and willingness to share his knowledge made the journey more enjoyable. I am grateful for the camaraderie we shared, which made the challenges of research more manageable and rewarding.

Moreover, I extend my deepest thanks to my parents and my brother, Behrouz, who have been my pillars of strength throughout this endeavour. Their unwavering belief in my abilities and constant encouragement motivated me to persevere, even during the most challenging times. My parents instilled in me the values of hard work and determination, while Behroz's support and understanding provided me with the emotional strength I needed to succeed.

Lastly, above all, I thank God for all the blessings bestowed upon me.

## 7. Appendices

**Appendix 1.** Classification of Iran's Provinces According to Income. (Created by the author)

Province	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
AZ1 *	13	13	13	13	13	13	13	13	13	12	12	13	12	12	12	12	12
AZ2 *	12	12	12	11	11	11	11	11	12	11	12	12	12	12	12	12	12
Ardabil	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11
Esfahan	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13
Ilam	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11
Bushehr *	11	11	12	12	12	12	12	12	12	12	12	13	13	13	13	13	13
Tehran	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14
Chaharmahal	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11
Khorasan	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13
Khozestan *	13	14	13	14	14	14	14	13	13	13	13	13	13	13	13	13	13
Zanjan	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11
Semnan	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11
Sistan	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11
Fars	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13
Iazvin	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11
Iom	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11
Kurdestan	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11
Kerman	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12
Kermanshah	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11
Kohgiluyeh *	13	13	13	13	13	13	12	12	12	12	12	11	11	11	11	11	11
Golestan	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11
Gilan	12	12	12	12	12	12	12	12	12	12	11	12	12	12	12	12	12
Lorestan	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11
Mazandaran *	13	13	13	12	12	12	12	13	13	13	12	13	13	12	13	13	13
Markazi *	12	12	12	12	11	12	11	11	11	11	11	12	12	12	12	12	12
Hormozgan *	11	11	11	12	11	11	11	11	11	11	12	12	12	12	12	12	12
Hamedan	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11
Yazd	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11

\* The provinces experienced instability during the period.

**Appendix 2.** Classification of Iran's Provinces According to population. (Created by the author)

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
Kohgiluyeh	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
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

\* The provinces experienced instability during the period.

**Appendix 3.** Mann-Kendall's test for Oil consumption in Provinces of Iran.  
(Created by the author)

<b>Series\Test</b>	<b>Kendall's tau</b>	<b>p-value</b>	<b>Sen's slope</b>
AZ1	-0.9649	< <b>0.0001</b>	-49553.8782
AZ2	-0.9649	< <b>0.0001</b>	-64596.8000
Ardabil	-0.9298	< <b>0.0001</b>	-13152.3463
Esfahan	-0.7661	< <b>0.0001</b>	-33821.4000
Ilam	-0.6140	<b>0.0003</b>	-7919.1917
Bushehr	-0.3216	0.0589	-2186.2630
Tehran	-0.9883	< <b>0.0001</b>	-129504.2000
Chaharmahal	-0.8830	< <b>0.0001</b>	-8517.5714
Khorasan	-0.7427	< <b>0.0001</b>	-53470.5466
Khozestan	-0.5556	<b>0.0010</b>	-6710.6978
Zanjan	-0.5673	<b>0.0008</b>	-10253.2231
Semnan	-0.9766	< <b>0.0001</b>	-5178.6404
Sistan	0.5789	<b>0.0006</b>	12312.6364
Fars	-0.7778	< <b>0.0001</b>	-21121.9333
Qazvin	-0.9181	< <b>0.0001</b>	-12930.6429
Qom	-0.8246	< <b>0.0001</b>	-19027.8095
Kurdestan	-0.8129	< <b>0.0001</b>	-26146.5000
Kerman	-0.7895	< <b>0.0001</b>	-25109.0000
Kermanshah	-0.8129	< <b>0.0001</b>	-23100.6667
Kohgiluyeh	-0.5088	<b>0.0026</b>	-3153.0000
Golestan	-0.8830	< <b>0.0001</b>	-10760.6643
Gilan	-0.9532	< <b>0.0001</b>	-29132.5833
Lorestan	-0.9532	< <b>0.0001</b>	-16197.7568
Mazandaran	-1.0000	< <b>0.0001</b>	-60913.5264
Markazi	-0.6608	< <b>0.0001</b>	-17831.6667
Hormozgan	0.0877	0.6243	1557.9091
Hamedan	-0.9415	< <b>0.0001</b>	-16611.1668
Yazd	-0.9298	< <b>0.0001</b>	-21571.7143

**Appendix 4.** Mann-Kendall's test for Gas consumption in Provinces of Iran.  
(Created by the author)

Series\Test	Kendall's		Sen's slope
	tau	p-value	
AZ1	0.7895	< <b>0.0001</b>	139.4551
AZ2	0.9181	< <b>0.0001</b>	137.1800
Ardabil	0.9181	< <b>0.0001</b>	37.6372
Esfahan	0.6725	< <b>0.0001</b>	101.7333
Ilam	1.0000	< <b>0.0001</b>	19.1200
Bushehr	0.9766	< <b>0.0001</b>	6.9571
Tehran	0.8363	< <b>0.0001</b>	417.6000
Chaharmahal	0.7076	< <b>0.0001</b>	23.6000
Khorasan	0.9298	< <b>0.0001</b>	197.7559
Khozestan	0.9181	< <b>0.0001</b>	44.8160
Zanjan	0.9298	< <b>0.0001</b>	31.5000
Semnan	0.8480	< <b>0.0001</b>	13.9571
Sistan	0.7836	< <b>0.0001</b>	0.7214
Fars	0.9649	< <b>0.0001</b>	88.4500
Qazvin	0.9064	< <b>0.0001</b>	36.5667
Qom	0.8480	< <b>0.0001</b>	21.0667
Kurdestan	0.9298	< <b>0.0001</b>	70.9483
Kerman	0.9766	< <b>0.0001</b>	53.4901
Kermanshah	0.9384	< <b>0.0001</b>	67.5000
Kohgiluyeh	0.9736	< <b>0.0001</b>	17.0000
Golestan	0.9415	< <b>0.0001</b>	44.1857
Gilan	0.8713	< <b>0.0001</b>	78.5990
Lorestan	0.8713	< <b>0.0001</b>	39.3659
Mazandaran	0.9181	< <b>0.0001</b>	156.5545
Markazi	0.7310	< <b>0.0001</b>	36.8083
Hormozgan	0.8790	< <b>0.0001</b>	0.4000
Hamedan	0.8129	< <b>0.0001</b>	48.8000
Yazd	0.9064	< <b>0.0001</b>	42.7357

**Appendix 5.** Mann-Kendall's test for Electricity consumption in Provinces of Iran. Created by the author

Series\Test	Kendall's		Sen's slope
	tau	p-value	
AZ1	0.8129	< <b>0.0001</b>	106.4000
AZ2	0.8480	< <b>0.0001</b>	80.2000
Ardabil	0.8480	< <b>0.0001</b>	28.6357
Esfahan	0.9181	< <b>0.0001</b>	199.2267
Ilam	0.9181	< <b>0.0001</b>	38.9333
Bushehr	0.9298	< <b>0.0001</b>	247.3333
Tehran	0.9532	< <b>0.0001</b>	808.4143
Chaharmahal	0.7661	< <b>0.0001</b>	18.6813
Khorasan	0.9298	< <b>0.0001</b>	269.6214
Khozestan	0.9532	< <b>0.0001</b>	846.6000
Zanjan	0.8012	< <b>0.0001</b>	27.9286
Semnan	0.9064	< <b>0.0001</b>	27.7400
Sistan	0.9532	< <b>0.0001</b>	206.4355
Fars	0.9415	< <b>0.0001</b>	268.5357
Qazvin	0.8363	< <b>0.0001</b>	42.0846
Qom	0.9766	< <b>0.0001</b>	71.9000
Kurdestan	0.9181	< <b>0.0001</b>	38.9286
Kerman	0.8363	< <b>0.0001</b>	167.5857
Kermanshah	0.8596	< <b>0.0001</b>	68.1685
Kohgiluyeh	0.9298	< <b>0.0001</b>	50.3500
Golestan	0.9181	< <b>0.0001</b>	83.3000
Gilan	0.9415	< <b>0.0001</b>	118.4172
Lorestan	0.9181	< <b>0.0001</b>	59.0700
Mazandaran	0.9415	< <b>0.0001</b>	197.1615
Markazi	0.8480	< <b>0.0001</b>	42.4813
Hormozgan	0.9883	< <b>0.0001</b>	333.9800
Hamedan	0.9064	< <b>0.0001</b>	42.6500
Yazd	0.9532	< <b>0.0001</b>	54.2231

**Appendix 6.** Mann-Kendall's test for CO<sub>2</sub> emissions in Provinces of Iran.  
(Created by the author)

Series\Test	Kendall's tau	p-value	Sen's slope
AZ1	0.5556	<b>0.0010</b>	220825.1472
AZ2	0.8129	< <b>0.0001</b>	297754.8859
Ardabil	0.7544	< <b>0.0001</b>	65195.1877
Esfahan	0.2047	0.2342	78752.6167
Ilam	1.0000	< <b>0.0001</b>	46302.3196
Bushehr	0.9766	< <b>0.0001</b>	17486.6134
Tehran	0.4269	<b>0.0118</b>	456905.7097
Chaharmahal	0.4035	<b>0.0174</b>	32434.3143
Khorasan	0.7778	< <b>0.0001</b>	315775.4362
Khozestan	0.8713	< <b>0.0001</b>	91042.1844
Zanjan	0.8363	< <b>0.0001</b>	50672.2083
Semnan	0.4152	<b>0.0143</b>	11383.6185
Sistan	0.7895	< <b>0.0001</b>	1894.8985
Fars	0.8713	< <b>0.0001</b>	151674.9600
Qazvin	0.6959	< <b>0.0001</b>	52080.1784
Qom	0.4620	<b>0.0064</b>	16985.7429
Kurdestan	0.9181	< <b>0.0001</b>	144157.6788
Kerman	0.9064	< <b>0.0001</b>	113013.6034
Kermanshah	0.8363	< <b>0.0001</b>	137918.8803
Kohgiluyeh	0.9298	< <b>0.0001</b>	34582.8086
Golestan	0.7895	< <b>0.0001</b>	72101.8502
Gilan	0.7778	< <b>0.0001</b>	125214.9549
Lorestan	0.6491	<b>0.0001</b>	73113.7527
Mazandaran	0.8596	< <b>0.0001</b>	306495.7643
Markazi	0.3567	<b>0.0358</b>	42085.8403
Hormozgan	0.9532	< <b>0.0001</b>	1082.9977
Hamedan	0.5789	<b>0.0006</b>	65288.9440
Yazd	0.8129	< <b>0.0001</b>	92546.5639

## 8. References

- Alajmi, R. G. (2022). Carbon emissions and electricity generation modeling in Saudi Arabia. *Environmental Science and Pollution Research*, 29(16), 23169–23179. <https://doi.org/10.1007/s11356-021-17354-0>
- Altouma, A., Bashir, B., Ata, B., Ocwa, A., Alsalman, A., Harsányi, E., & Mohammed, S. (2024). An environmental impact assessment of Saudi Arabia's vision 2030 for sustainable urban development: A policy perspective on greenhouse gas emissions. *Environmental and Sustainability Indicators*, 21. <https://doi.org/10.1016/j.indic.2023.100323>
- Araghi, M. , & S Barkhordari. (2012). An evaluation of the welfare effects of reducing energy subsidies in Iran. *Elsevier*. <https://www.sciencedirect.com/science/article/pii/S0301421512004041>
- Arellano, M., & Bond, S. (1991). Some Tests of Specification for Panel Data: Monte Carlo Evidence and an Application to Employment Equations. *The Review of Economic Studies*, 58(2), 277–297. <https://doi.org/10.2307/2297968>
- Arellano, M., & Bover, O. (1995). Another look at the instrumental variable estimation of error-components models. *Journal of Econometrics*, 68(1), 29–51. [https://doi.org/10.1016/0304-4076\(94\)01642-D](https://doi.org/10.1016/0304-4076(94)01642-D)
- Aryanpur, V., Fattahi, M., Mamipour, S., Ghahremani, M., Gallachóir, B., Bazilian, M. D., & Glynn, J. (2022). How energy subsidy reform can drive the Iranian power sector towards a low-carbon future. *Energy Policy*, 169. <https://doi.org/10.1016/j.enpol.2022.113190>
- Aryanpur, V., Ghahremani, M., Mamipour, S., Fattahi, M., Ó Gallachóir, B., Bazilian, M. D., & Glynn, J. (2022). Ex-post analysis of energy subsidy removal through integrated energy systems modelling. *Renewable and Sustainable Energy Reviews*, 158. <https://doi.org/10.1016/j.rser.2022.112116>
- Ata, B., Pakrooh, P., Barkat, A., Benhizia, R., & Pénczes, J. (2022). Inequalities in Regional Level Domestic CO2 Emissions and Energy Use: A Case Study of Iran. *Energies* 2022, Vol. 15, Page 3902, 15(11), 3902. <https://doi.org/10.3390/EN15113902>

- Ata, B., Pakrooh, P., & Pénczes, J. (2023). Driving factors of energy related CO<sub>2</sub> emissions at a regional level in the residential sector of Iran. *Scientific Reports*, *13*(1). <https://doi.org/10.1038/s41598-023-44975-x>
- Bai, Y., Deng, X., Gibson, J., Zhao, Z., & Xu, H. (2019). How does urbanization affect residential CO<sub>2</sub> emissions? An analysis on urban agglomerations of China. *Journal of Cleaner Production*, *209*, 876–885. <https://doi.org/10.1016/J.JCLEPRO.2018.10.248>
- Balaras, C. A., Gaglia, A. G., Georgopoulou, E., Mirasgedis, S., Sarafidis, Y., & Lalas, D. P. (2007). European residential buildings and empirical assessment of the Hellenic building stock, energy consumption, emissions and potential energy savings. *Building and Environment*, *42*(3), 1298–1314. <https://doi.org/10.1016/J.BUILDENV.2005.11.001>
- Balezentis, T. (2020). Shrinking ageing population and other drivers of energy consumption and CO<sub>2</sub> emission in the residential sector: A case from Eastern Europe. *Energy Policy*, *140*, 111433. <https://doi.org/10.1016/J.ENPOL.2020.111433>
- Barkhordar, Z. A. (2019). Evaluating the economy-wide effects of energy efficient lighting in the household sector of Iran. *Energy Policy*, *127*, 125–133. <https://doi.org/10.1016/j.enpol.2018.11.053>
- Basel Committee on Banking Supervision. (2021). *Climate-related financial risks—measurement methodologies*.
- BBC. (2021). *Iran bans cryptocurrency mining for four months after blackouts*. <https://www.bbc.com/news/world-middle-east-57260829>
- Belaïd, F., & Mikayilov, J. I. (2024). Closing the Efficiency Gap: Insights into curbing the direct rebound effect of residential electricity consumption in Saudi Arabia. *Energy Economics*, *135*. <https://doi.org/10.1016/j.eneco.2024.107647>
- Bell, A., & Jones, K. (2015). Explaining Fixed Effects: Random Effects Modeling of Time-Series Cross-Sectional and Panel Data\*. *Political Science Research and Methods*, *3*(1), 133–153. <https://doi.org/10.1017/PSRM.2014.7>
- Berezvai, Z., Hortay, O., & Szöke, T. (2022). The impact of COVID-19 measures on intraday electricity load curves in the European Union: A panel approach. *Sustainable Energy, Grids and Networks*, *32*, 100930. <https://doi.org/10.1016/J.SEGAN.2022.100930>
- Bianco, V., Cascetta, F., Marino, A., & Nardini, S. (2019). Understanding energy consumption and carbon emissions in Europe: A focus on inequality issues. *Energy*, *170*, 120–130. <https://doi.org/10.1016/j.energy.2018.12.120>

- Bianco, V., Proskuryakova, L., & Starodubtseva, A. (2021). Energy inequality in the Eurasian Economic Union. *Renewable and Sustainable Energy Reviews*, 146. <https://doi.org/10.1016/j.rser.2021.111155>
- Billio, M., Casarin, R., Costola, M., & Veggente, V. (2024). Learning from experts: Energy efficiency in residential buildings. *Energy Economics*, 136, 107650. <https://doi.org/10.1016/j.eneco.2024.107650>
- Billio, M., Costola, M., Hristova, I., Latino, C., & Pelizzon, L. (2021). Inside the ESG ratings: (Dis)agreement and performance. *Corporate Social Responsibility and Environmental Management*, 28(5), 1426–1445. <https://doi.org/10.1002/csr.2177>
- Bloomberg. (2024). *Iran's Oil and Gas Infrastructure*. <https://www.bloomberg.com/news/articles/2024-10-03/here-s-a-map-of-iran-s-most-critical-oil-and-gas-infrastructure>.
- Bourguignon, F. (1979). *Decomposable Income Inequality Measures* (Vol. 47, Issue 4).
- BP. (2022). *BP Statistical Review of World Energy*. <https://www.bp.com/en/global/corporate/energy-economics.html>
- Büchs, M., & Schnepf, S. V. (2013). Who emits most? Associations between socio-economic factors and UK households' home energy, transport, indirect and total CO2 emissions. *Ecological Economics*, 90, 114–123. <https://doi.org/10.1016/J.ECOLECON.2013.03.007>
- Calvin, K., Dasgupta, D., Krinner, G., Mukherji, A., Thorne, P. W., Trisos, C., Romero, J., Aldunce, P., Barrett, K., Blanco, G., Cheung, W. W. L., Connors, S., Denton, F., Diongue-Niang, A., Dodman, D., Garschagen, M., Geden, O., Hayward, B., Jones, C., ... Ha, M. (2023). *IPCC, 2023: Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, H. Lee and J. Romero (eds.)]. IPCC, Geneva, Switzerland.* (P. Arias, M. Bustamante, I. Elgizouli, G. Flato, M. Howden, C. Méndez-Vallejo, J. J. Pereira, R. Pichs-Madruga, S. K. Rose, Y. Saheb, R. Sánchez Rodríguez, D. Ürge-Vorsatz, C. Xiao, N. Yassaa, J. Romero, J. Kim, E. F. Haites, Y. Jung, R. Stavins, ... C. Péan, Eds.). <https://doi.org/10.59327/IPCC/AR6-9789291691647>
- Chen, H., Qi, S., & Tan, X. (2022). Decomposition and prediction of China's carbon emission intensity towards carbon neutrality: From perspectives of national, regional and sectoral level. *Science of the Total Environment*, 825. <https://doi.org/10.1016/j.scitotenv.2022.153839>
- Chen, J., Lin, Y., Wang, X., Mao, B., & Peng, L. (2022). Direct and Indirect Carbon Emission from Household Consumption Based on LMDI and SDA Model: A

Decomposition and Comparison Analysis. *Energies* 2022, Vol. 15, Page 5002, 15(14), 5002. <https://doi.org/10.3390/EN15145002>

Chen, L., Xu, L., Wang, Y., Xia, L., & Yang, Z. (2023). Inequality and its driving forces in residential CO<sub>2</sub> emission: Perspective of energy use pattern. *Journal of Cleaner Production*, 414. <https://doi.org/10.1016/j.jclepro.2023.137538>

Chen, L., Xu, L., & Yang, Z. (2019). Inequality of industrial carbon emissions of the urban agglomeration and its peripheral cities: A case in the Pearl River Delta, China. *Renewable and Sustainable Energy Reviews*, 109, 438–447. <https://doi.org/10.1016/j.rser.2019.04.010>

Chen, Y., & Jiang, L. (2022). Influencing Factors of Direct Carbon Emissions of Households in Urban Villages in Guangzhou, China. *International Journal of Environmental Research and Public Health*, 19(24). <https://doi.org/10.3390/IJERPH192417054>

Chun-sheng, Z., Shu-wen, N., & Xin, Z. (2012). Effects of household energy consumption on environment and its influence factors in rural and urban areas. *Energy Procedia*, 14, 805–811. <https://doi.org/10.1016/J.EGYPRO.2011.12.1015>

ClipperData. (2022, July). *ClipperData LLC*. 2022.

Cutz, L., Masera, O., Santana, D., & Faaij, A. P. C. (2017). Switching to efficient technologies in traditional biomass intensive countries: The resultant change in emissions. *Energy*, 126, 513–526. <https://doi.org/10.1016/j.energy.2017.03.025>

Danish, M. S. S., Senjyu, T., Ibrahim, A. M., Ahmadi, M., & Howlader, A. M. (2019). A managed framework for energy-efficient building. *Journal of Building Engineering*, 21, 120–128. <https://doi.org/10.1016/j.jobbe.2018.10.013>

Dehdar, F., Silva, N., Fuinhas, J., Koengkan, M., Energies, N. N.-, & 2022, undefined. (2022). The Impact of Technology and Government Policies on OECD Carbon Dioxide Emissions. *Mdpi.Com*. <https://doi.org/10.3390/en15228486>

Ding, Q., Xiao, X., & Kong, D. (2023). Estimating energy-related CO<sub>2</sub> emissions using a novel multivariable fuzzy grey model with time-delay and interaction effect characteristics. *Energy*, 263. <https://doi.org/10.1016/j.energy.2022.126005>

Donglan, Z., Dequn, Z., & Peng, Z. (2010). Driving forces of residential CO<sub>2</sub> emissions in urban and rural China: An index decomposition analysis. *Energy Policy*, 38(7), 3377–3383. <https://doi.org/10.1016/J.ENPOL.2010.02.011>

Dou, Y., Zhao, J., Dong, X., & Dong, K. (2021). Quantifying the impacts of energy inequality on carbon emissions in China: A household-level analysis. *Energy Economics*, 102. <https://doi.org/10.1016/j.eneco.2021.105502>

- Duan, C., & Chen, B. (2018). Analysis of global energy consumption inequality by using Lorenz curve. *Energy Procedia*, 152, 750–755.  
<https://doi.org/10.1016/j.egypro.2018.09.240>
- Duarte, R., Miranda-Buetas, S., & Sarasa, C. (2021). Household consumption patterns and income inequality in EU countries: Scenario analysis for a fair transition towards low-carbon economies. *Energy Economics*, 104.  
<https://doi.org/10.1016/j.eneco.2021.105614>
- Duro, J. A., & Padilla, E. (2011). Inequality across countries in energy intensities: An analysis of the role of energy transformation and final energy consumption. *Energy Economics*, 33(3), 474–479. <https://doi.org/10.1016/j.eneco.2010.12.008>
- energy Agency, I. (2021). *Statistics report Key World Energy Statistics 2021*.  
*Energy performance of buildings*. (2021). Eceee.Org/Policy-Areas/Buildings/.  
[eceee.org/policy-areas/Buildings/](https://www.eceee.org/policy-areas/Buildings/)
- European Commission. (2023). *EDGAR (Emissions Database for Global Atmospheric Research) Community GHG database, comprising IEA-EDGAR CO<sub>2</sub>, EDGAR CH<sub>4</sub>*.
- European Economic and Social Committee. (2010). *Energy poverty—the impact of liberalisation and the economic crisis, CESE 990/2010—TEN/420 Exploratory Opinion*.
- European Economic and Social Committee. (2013). *Opinion of the European Economic and Social Committee on ‘For coordinated European measures to prevent and combat energy poverty’ (own-initiative opinion)*,.
- Facts Global Energy. (2021). *Iran’s Oil and Gas Monthly Report*.
- Fallah, B., Sodoudi, S., Russo, E., Kirchner, I., & Cubasch, U. (2017). Towards modeling the regional rainfall changes over Iran due to the climate forcing of the past 6000 years. *Quaternary International*, 429, 119–128.  
<https://doi.org/10.1016/j.quaint.2015.09.061>
- Fan, J., Ran, A. X. L., & 2019, undefined. (2019). A study on the factors affecting China’s direct household carbon emission and comparison of regional differences. *Mdpi.Com*. <https://doi.org/10.3390/su11184919>
- Farajzadeh, Z., & Nematollahi, M. A. (2018). Energy intensity and its components in Iran: Determinants and trends. *Energy Economics*, 73, 161–177.  
<https://doi.org/10.1016/j.eneco.2018.05.021>

- Fatourehchi, D., Noguchi, M., & Doloi, H. (2022). Iranian Household Electricity Use Compared to Selected Countries. *Encyclopedia*, 2(4), 1637–1665.  
<https://doi.org/10.3390/encyclopedia2040112>
- Fattouh, B., & El-Katiri, L. (2013). Energy subsidies in the Middle East and North Africa. *Energy Strategy Reviews*, 2(1), 108–115.  
<https://doi.org/10.1016/j.esr.2012.11.004>
- Ferentinos, K., Gibberd, A., & Guin, B. (2023). Stranded houses? The price effect of a minimum energy efficiency standard. *Energy Economics*, 120.  
<https://doi.org/10.1016/j.eneco.2023.106555>
- Gallego-Schmid, A., Chen, H. M., Sharmina, M., & Mendoza, J. M. F. (2020). Links between circular economy and climate change mitigation in the built environment. In *Journal of Cleaner Production* (Vol. 260). Elsevier Ltd.  
<https://doi.org/10.1016/j.jclepro.2020.121115>
- Gerres, T., Chaves, J. P., & Linares, P. (2023). The effects of industrial policymaking on the economics of low-emission technologies: The TRANSid model. *Energy Storage and Saving*, 2(3), 513–521. <https://doi.org/10.1016/j.enss.2023.03.003>
- Ghorbani, N., Aghahosseini, A., & Breyer, C. (2020). Assessment of a cost-optimal power system fully based on renewable energy for Iran by 2050 – Achieving zero greenhouse gas emissions and overcoming the water crisis. *Renewable Energy*, 146, 125–148. <https://doi.org/10.1016/j.renene.2019.06.079>
- Global Covenant of Mayors Common Reporting Framework*. (2023).  
<https://www.globalcovenantofmayors.org/our-initiatives/data4cities/common-global-reporting-framework/>
- Global Petrol Prices. (2022). *fuel price data*.  
[https://www.globalpetrolprices.com/Data\\_download.php](https://www.globalpetrolprices.com/Data_download.php)
- Greene, W. (2012). *Econometric Analysis* (7th Edition).  
[https://www.scirp.org/\(S\(lz5mqp453edsnp55rrgjt55.\)\)/reference/referencespapers.aspx?referenceid=2013974](https://www.scirp.org/(S(lz5mqp453edsnp55rrgjt55.))/reference/referencespapers.aspx?referenceid=2013974)
- Guan, X., Guo, S., Xiong, J., Jia, G., & Fan, J. L. (2023). Energy-related CO2 emissions of urban and rural residential buildings in China: A provincial analysis based on end-use activities. *Journal of Building Engineering*, 64.  
<https://doi.org/10.1016/j.jobe.2022.105686>
- Guin, B., Korhonen, P., & Moktan, S. (2022). Risk differentials between green and brown assets? *Economics Letters*, 213.  
<https://doi.org/10.1016/j.econlet.2022.110320>

- Guo, Y., Uhde, H., & Wen, W. (2023). Uncertainty of energy consumption and CO2 emissions in the building sector in China. *Sustainable Cities and Society*, 97. <https://doi.org/10.1016/j.scs.2023.104728>
- Guo, Y. Y. (2022). Revisiting the building energy consumption in China: Insights from a large-scale national survey. *Energy for Sustainable Development*, 68, 76–93. <https://doi.org/10.1016/j.esd.2022.03.005>
- Hafeznia, H., Pourfayaz, F., & Maleki, A. (2017). An assessment of Iran's natural gas potential for transition toward low-carbon economy. In *Renewable and Sustainable Energy Reviews* (Vol. 79, pp. 71–81). Elsevier Ltd. <https://doi.org/10.1016/j.rser.2017.05.042>
- Hajilary, N., Shahi, A., & Rezakazemi, M. (2018). Evaluation of socio-economic factors on CO2 emissions in Iran: Factorial design and multivariable methods. *Journal of Cleaner Production*, 189, 108–115. <https://doi.org/10.1016/J.JCLEPRO.2018.04.067>
- Hansen, C. M. (2007). Methods of characterization - surfaces. *Hansen Solubility Parameters: A Users Handbook, Second Edition*, 113–123. <https://doi.org/10.1201/9781420006834/HANSEN-SOLUBILITY-PARAMETERS-CHARLES-HANSEN>
- Hashmi, R., & Alam, K. (2019). Dynamic relationship among environmental regulation, innovation, CO2 emissions, population, and economic growth in OECD countries: A panel investigation. *Journal of Cleaner Production*, 231, 1100–1109. <https://doi.org/10.1016/J.JCLEPRO.2019.05.325>
- Hassan, S. A., & Nosheen, M. (2019). Estimating the Railways Kuznets Curve for high income nations—A GMM approach for three pollution indicators. *Energy Reports*, 5, 170–186. <https://doi.org/10.1016/J.EGYR.2019.01.001>
- Haugen, M., Blaisdell-Pijuan, P. L., Botterud, A., Levin, T., Zhou, Z., Belsnes, M., Korpås, M., & Somani, A. (2024). Power market models for the clean energy transition: State of the art and future research needs. *Applied Energy*, 357. <https://doi.org/10.1016/j.apenergy.2023.122495>
- Hosseini, S. M., Saifoddin, A., Shirmohammadi, R., & Aslani, A. (2019). Forecasting of CO2 emissions in Iran based on time series and regression analysis. *Energy Reports*, 5, 619–631. <https://doi.org/10.1016/j.egy.2019.05.004>
- Huang, R., & Tian, L. (2021). CO2 emissions inequality through the lens of developing countries. *Applied Energy*, 281. <https://doi.org/10.1016/j.apenergy.2020.116043>
- Hussain, A., Memon, J. A., Murshed, M., Alam, M. S., Mehmood, U., Alam, M. N., Rahman, M., & Hayat, U. (2022). A time series forecasting analysis of overall and sector-based natural gas demand: a developing South Asian economy case.

*Environmental Science and Pollution Research*, 29(47), 71676–71687.  
<https://doi.org/10.1007/s11356-022-20861-3>

IEA. (2014, February 25). *International Energy Agency*. (<http://Www.Iea.Org/Statistics/>).

IEA. (2016). *Statistics Report*. International Energy Agency.

IEA. (2021). *Net zero by 2050: a roadmap for the global energy sector*.

IEA. (2023). *Value of fossil-fuel subsidies by fuel in the top 25 countries*.

<https://Www.Iea.Org/Data-and-Statistics/Charts/Value-of-Fossil-Fuel-Subsidies-by-Fuel-in-the-Top-25-Countries-2022>, Licence: CC BY 4.0.

Im, K. S., Pesaran, M. H., & Shin, Y. (2003). Testing for unit roots in heterogeneous panels. *Journal of Econometrics*, 115(1), 53–74. [https://doi.org/10.1016/S0304-4076\(03\)00092-7](https://doi.org/10.1016/S0304-4076(03)00092-7)

Imran, M., Zahid, A., Mouneer, S., Özçatalbaş, O., Haq, S. U., Shahbaz, P., Muzammil, M., & Murtaza, M. R. (2022). Relationship between Household Dynamics, Biomass Consumption, and Carbon Emissions in Pakistan. *Sustainability 2022, Vol. 14, Page 6762, 14(11), 6762*. <https://doi.org/10.3390/SU14116762>

International Energy Agency. (2023). *World Energy Outlook 2023*. [www.iea.org/terms](http://www.iea.org/terms)

Ito, K. (2017). CO2 emissions, renewable and non-renewable energy consumption, and economic growth: Evidence from panel data for developing countries. *International Economics*, 151, 1–6. <https://doi.org/10.1016/J.INTECO.2017.02.001>

JD Sargan. (1958). The estimation of economic relationships using instrumental variables. *JSTOR*. <https://www.jstor.org/stable/1907619>

Jiao, J., Song, J., & Ding, T. (2024). The impact of synergistic development of renewable energy and digital economy on energy intensity: Evidence from 33 countries. *Energy*, 295. <https://doi.org/10.1016/j.energy.2024.130997>

JRC, I. (2023). *EDGAR (Emissions Database for Global Atmospheric Research)*. [https://Edgar.Jrc.Ec.Europa.Eu/Report\\_2023](https://Edgar.Jrc.Ec.Europa.Eu/Report_2023).

K Hadri. (2000). Testing for stationarity in heterogeneous panel data. *Wiley Online Library*, 3(2), 148–161. <https://doi.org/10.1111/1368-423X.00043>

Kamal, A., Al-Ghamdi, S. G., & Koç, M. (2019). Role of energy efficiency policies on energy consumption and CO2 emissions for building stock in Qatar. *Journal of Cleaner Production*, 235, 1409–1424. <https://doi.org/10.1016/J.JCLEPRO.2019.06.296>

- Kao, C. (1999). Spurious regression and residual-based tests for cointegration in panel data. *Journal of Econometrics*, 90(1), 1–44. [https://doi.org/10.1016/S0304-4076\(98\)00023-2](https://doi.org/10.1016/S0304-4076(98)00023-2)
- Karpinska, L., & Śmiech, S. (2022). Shadow of single-family homes: Analysis of the determinants of Polish households' energy-related CO2 emissions. *Energy and Buildings*, 277, 112550. <https://doi.org/10.1016/J.ENBUILD.2022.112550>
- Kasman, A., & Duman, Y. S. (2015). CO2 emissions, economic growth, energy consumption, trade and urbanization in new EU member and candidate countries: A panel data analysis. *Economic Modelling*, 44, 97–103. <https://doi.org/10.1016/J.ECONMOD.2014.10.022>
- Kaviani Rad, Murad. K. Y. F. H. and K. S. (2017). Explaining the Consequences of Climate Change Change in the Central Iranian Watershed Area. *Journal of Applied Research in Geographical Sciences*, 45.
- Kazemi, M. (2018). *Factors influencing energy reduction in buildings*. Shahid Beheshti University.
- Kenny, R., Law, C., & Pearce, J. M. (2010). Towards real energy economics: Energy policy driven by life-cycle carbon emission. *Energy Policy*, 38(4), 1969–1978. <https://doi.org/10.1016/j.enpol.2009.11.078>
- Khan, Z., Ali, S., Dong, K., & Li, R. Y. M. (2021). How does fiscal decentralization affect CO2 emissions? The roles of institutions and human capital. *Energy Economics*, 94. <https://doi.org/10.1016/j.eneco.2020.105060>
- Kim, J. H. (2019). Multicollinearity and misleading statistical results. *Korean Journal of Anesthesiology*, 72(6), 558–569. <https://doi.org/10.4097/KJA.19087>
- Kostakis, I., Lolos, S., & Sardianou, E. (2021). Residential natural gas demand: Assessing the evidence from Greece using pseudo-panels, 2012–2019. *Energy Economics*, 99, 105301. <https://doi.org/10.1016/J.ENECO.2021.105301>
- Kulczycka, J., Dziobek, E., & Nowosielski, M. (2023). Promotion and implementation of Polish mining investments in foreign markets on the example of Latin America. *Energy Storage and Saving*, 2(4), 608–614. <https://doi.org/10.1016/j.enss.2023.08.008>
- Labra, R., Torrecillas, C., Labra, R., & Torrecillas, C. (2018). Estimating dynamic Panel data. A practical approach to perform long panels. *Revista Colombiana de Estadística*, 41(1), 31–52. <https://doi.org/10.15446/RCE.V41N1.61885>
- Levin, A., Lin, C. F., & Chu, C. S. J. (2002). Unit root tests in panel data: asymptotic and finite-sample properties. *Journal of Econometrics*, 108(1), 1–24. [https://doi.org/10.1016/S0304-4076\(01\)00098-7](https://doi.org/10.1016/S0304-4076(01)00098-7)

- Li, D., Cao, L., Zhou, Z., Zhao, K., Du, Z., & Chen, Y. (2024). Correlating CO<sub>2</sub> emissions of cities with the inter-city carbon compensation mechanism: a regional perspective in the middle reaches of the Yangtze River (MRYR), China. *Environment, Development and Sustainability*, 26(4), 9185–9216. <https://doi.org/10.1007/s10668-023-03089-0>
- Li, H., Qiu, P., & Wu, T. (2021). The regional disparity of per-capita CO<sub>2</sub> emissions in China's building sector: An analysis of macroeconomic drivers and policy implications. *Energy and Buildings*, 244. <https://doi.org/10.1016/j.enbuild.2021.111011>
- Li, Q., Wu, S., Lei, Y., & Li, S. (2020). Dynamic features and driving forces of indirect CO<sub>2</sub> emissions from Chinese household: A comparative and mitigation strategies analysis. *Science of The Total Environment*, 704, 135367. <https://doi.org/10.1016/J.SCITOTENV.2019.135367>
- Li, R., Han, X., & Wang, Q. (2023). Do technical differences lead to a widening gap in China's regional carbon emissions efficiency? Evidence from a combination of LMDI and PDA approach. *Renewable and Sustainable Energy Reviews*, 182. <https://doi.org/10.1016/j.rser.2023.113361>
- Liu, Y. Z., Su, C., & Zhang, W. W. (2024). A multi-region analysis on drivers of energy related CO<sub>2</sub> emissions in India from 2013 to 2021. *Applied Energy*, 355. <https://doi.org/10.1016/j.apenergy.2023.122353>
- Lotfalipour, M. R., Falahi, M. A., & Ashena, M. (2010). Economic growth, CO<sub>2</sub> emissions, and fossil fuels consumption in Iran. *Energy*, 35(12), 5115–5120. <https://doi.org/10.1016/j.energy.2010.08.004>
- Machard, A., Salvati, A., P. Tootkaboni, M., Gaur, A., Zou, J., Wang, L. L., Baba, F., Ge, H., Bre, F., Bozonnet, E., Corrado, V., Luo, X., Levinson, R., Lee, S. H., Hong, T., Salles Olinger, M., Machado, R. M. e S., da Guarda, E. L. A., Veiga, R. K., ... Holzer, P. (2024). Typical and extreme weather datasets for studying the resilience of buildings to climate change and heatwaves. *Scientific Data*, 11(1), 531. <https://doi.org/10.1038/s41597-024-03319-8>
- Maddala, G. S., & Wu, S. (1999). A Comparative Study of Unit Root Tests with Panel Data and a New Simple Test. *Oxford Bulletin of Economics and Statistics*, 61(S1), 631–652. <https://doi.org/10.1111/1468-0084.0610S1631>
- Mancinelli, C., Manno, M., Salvatori, M., & Zaccagnini, A. (2023). Thermal energy storage as a way to improve transcritical CO<sub>2</sub> heat pump performance by means of heat recovery cycles. *Energy Storage and Saving*, 2(3), 532–539. <https://doi.org/10.1016/j.enss.2023.06.003>

- Mann, H. B. (1945). *Nonparametric Tests Against Trend* (Vol. 13, Issue 3).  
<https://www.jstor.org/stable/1907187>
- Mansouri Daneshvar, M. R., Ebrahimi, M., & Nejadsoleymani, H. (2019). An overview of climate change in Iran: facts and statistics. *Environmental Systems Research*, 8(1). <https://doi.org/10.1186/s40068-019-0135-3>
- Masera, O. R., Bailis, R., Drigo, R., Ghilardi, A., & Ruiz-Mercado, I. (2015). Environmental Burden of Traditional Bioenergy Use. *Annual Review of Environment and Resources*, 40, 121–150. <https://doi.org/10.1146/annurev-environ-102014-021318>
- Meangbua, O., Dhakal, S., & Kuwornu, J. K. M. (2019). Factors influencing energy requirements and CO2 emissions of households in Thailand: A panel data analysis. *Energy Policy*, 129, 521–531. <https://doi.org/10.1016/J.ENPOL.2019.02.050>
- Mi, Z., Zheng, J., Meng, J., Ou, J., Hubacek, K., Liu, Z., Coffman, D. M., Stern, N., Liang, S., & Wei, Y. M. (2020). Economic development and converging household carbon footprints in China. *Nature Sustainability*, 3(7), 529–537. <https://doi.org/10.1038/s41893-020-0504-y>
- Miao, L. (2017). Examining the impact factors of urban residential energy consumption and CO2 emissions in China – Evidence from city-level data. *Ecological Indicators*, 73, 29–37. <https://doi.org/10.1016/J.ECOLIND.2016.09.031>
- Miao, L., Gu, H., Zhang, X., Zhen, W., & Wang, M. (2019). Factors causing regional differences in China’s residential CO 2 emissions—evidence from provincial data. *Journal of Cleaner Production*, 224, 852–863. <https://doi.org/10.1016/j.jclepro.2019.03.271>
- Middle East Economic Survey. (2022a). *Iran Dreams Up 14GW Renewables Target*.
- Middle East Economic Survey. (2022b). *Iran’s Energy Sector: Lots of Bluster But Limited Progress*.
- Millimet, D. L. (2003). Assessing the empirical impact of environmental federalism. *Journal of Regional Science*, 43(4), 711–733. <https://doi.org/10.1111/j.0022-4146.2003.00317.x>
- Ministry of Energy of Iran. (2021). *Annuals Energy Balance Sheet*.
- Mirzaei, M., & Bekri, M. (2017). Energy consumption and CO2 emissions in Iran, 2025. *Environmental Research*, 154, 345–351. <https://doi.org/10.1016/j.envres.2017.01.023>
- Mitić, P., Fedajev, A., Radulescu, M., & Rehman, A. (2023). The relationship between CO2 emissions, economic growth, available energy, and employment in SEE

countries. *Environmental Science and Pollution Research*, 30(6), 16140–16155.  
<https://doi.org/10.1007/s11356-022-23356-3>

Mohammadnejad, M., Ghazvini, M., Mahlia, T. M. I., & Andriyana, A. (2011). A review on energy scenario and sustainable energy in Iran. In *Renewable and Sustainable Energy Reviews* (Vol. 15, Issue 9, pp. 4652–4658).  
<https://doi.org/10.1016/j.rser.2011.07.087>

Mohammed, S., Gill, A. R., Ghosal, K., Al-Dalahmeh, M., Alsafadi, K., Szabó, S., Oláh, J., Alkerdi, A., Ocwa, A., & Harsanyi, E. (2024). Assessment of the environmental kuznets curve within EU-27: Steps toward environmental sustainability (1990–2019). *Environmental Science and Ecotechnology*, 18.  
<https://doi.org/10.1016/j.ese.2023.100312>

Mohammed, S., Gill, A. R., Ghosal, K., Al-Dalahmeh, M., Alsafadi, K., Szilárd, S., Oláh, J., Alkerdi, A., Ocwa, A., & Harsanyi, E. (2023). Assessment of the environmental kuznets curve within EU-27: Steps toward environmental sustainability (1990–2019). *Environmental Science and Ecotechnology*, 100312.  
<https://doi.org/10.1016/j.ese.2023.100312>

Moshiri, S. (2015). The effects of the energy price reform on households consumption in Iran. *Energy Policy*, 79, 177–188. <https://doi.org/10.1016/j.enpol.2015.01.012>

Mu, R. (2018). Bounded rationality in the developmental trajectory of environmental target policy in China, 1972-2016. *Sustainability (Switzerland)*, 10(1).  
<https://doi.org/10.3390/su10010199>

Muhammad, B. (2019). Energy consumption, CO2 emissions and economic growth in developed, emerging and Middle East and North Africa countries. *Energy*, 179, 232–245. <https://doi.org/10.1016/J.ENERGY.2019.03.126>

Muzayanah, I. F. U., Lean, H. H., Hartono, D., Indraswari, K. D., & Partama, R. (2022). Population density and energy consumption: A study in Indonesian provinces. *Heliyon*, 8(9), e10634. <https://doi.org/10.1016/J.HELIYON.2022.E10634>

N Shrestha. (2020). Detecting multicollinearity in regression analysis. *American Journal of Applied Mathematics and Statistics*, 8(2), 39–42. <https://doi.org/10.12691/ajams-8-2-1>

Nejat, P., Jomehzadeh, F., Taheri, M. M., Gohari, M., & Muhd, M. Z. (2015). A global review of energy consumption, CO2 emissions and policy in the residential sector (with an overview of the top ten CO2 emitting countries). In *Renewable and Sustainable Energy Reviews* (Vol. 43, pp. 843–862). Elsevier Ltd.  
<https://doi.org/10.1016/j.rser.2014.11.066>

Oberheitmann, A. (2012). CO2-emission reduction in China's residential building sector and contribution to the national climate change mitigation targets in 2020.

*Mitigation and Adaptation Strategies for Global Change*, 17(7), 769–791.  
<https://doi.org/10.1007/s11027-011-9343-5>

Office of Promoting and Development of National Building Regulations. (2004). *The 19th issue of national building regulations: energy saving in buildings*.

Oil & Gas Journal. (2021). Worldwide look at reserves and production. *Oil & Gas Journal*.

Pablo-Romero, M. del P., Pozo-Barajas, R., & Yñiguez, R. (2017). Global changes in residential energy consumption. *Energy Policy*, 101, 342–352.  
<https://doi.org/10.1016/j.enpol.2016.10.032>

Padilla, E., & Duro, J. A. (2013). Explanatory factors of CO<sub>2</sub> per capita emission inequality in the European Union. *Energy Policy*, 62, 1320–1328.  
<https://doi.org/10.1016/j.enpol.2013.07.018>

Padilla, E., & Serrano, A. (2006). Inequality in CO<sub>2</sub> emissions across countries and its relationship with income inequality: A distributive approach. *Energy Policy*, 34(14), 1762–1772. <https://doi.org/10.1016/j.enpol.2004.12.014>

Pakrooh, P., Pishbahar, E., Hayati, B., & Nematian, J. (2021). Managing CO<sub>2</sub> Emissions through Focus on Energy Policies: Fresh Evidence from Iran's Agriculture Sector. *Environmental Energy and Economic Research*, 5(3), 1–20.  
<https://doi.org/10.22097/EEER.2021.277615.1190>

panels, J. B.-, cointegration, panel, panels, and dynamic, & 2001, undefined. (2001). The local power of some unit root tests for panel data. *Emerald.Com*.  
[https://www.emerald.com/insight/content/doi/10.1016/S0731-9053\(00\)15006-6/full/html](https://www.emerald.com/insight/content/doi/10.1016/S0731-9053(00)15006-6/full/html)

Park, J., & Yun, S. J. (2022). Social determinants of residential electricity consumption in Korea: Findings from a spatial panel model. *Energy*, 239.  
<https://doi.org/10.1016/j.energy.2021.122272>

Pedroni P. (2004). Panel cointegration: asymptotic and finite sample properties of pooled time series tests with an application to the PPP hypothesis. *Cambridge.Org*.  
<https://doi.org/10.1017/S0266466604203073>

Pesaran, M. H. (2007). A simple panel unit root test in the presence of cross-section dependence. *Journal of Applied Econometrics*, 22(2), 265–312.  
<https://doi.org/10.1002/JAE.951>

Pesaran, M. H. (2008). An Autoregressive Distributed-Lag Modelling Approach to Cointegration Analysis. In *Econometrics and Economic Theory in the 20th Century: The Ragnar Frisch Centennial Symposium* (pp. 371–413). Cambridge University Press. <https://doi.org/10.1017/ccol0521633230.011>

- Pesaran, M. H. (2021). General diagnostic tests for cross-sectional dependence in panels. *Empirical Economics*, 60(1), 13–50. <https://doi.org/10.1007/S00181-020-01875-7>
- Prol-Godoy, I., Picallo-Perez, A., Sala-Lizarraga, J. M., & Rey-Martínez, J. (2024). Experimental test of a building thermal system for preventive maintenance based on thermoeconomic analysis. *Energy Storage and Saving*, 3(1), 42–51. <https://doi.org/10.1016/j.enss.2023.08.002>
- Puntoon, W., Tarkhamtham, P., & Tansuchat, R. (2022). The impacts of economic growth, industrial production, and energy consumption on CO2 emissions: A case study of leading CO2 emitting countries. *Energy Reports*, 8, 414–419. <https://doi.org/10.1016/J.EGYR.2022.10.219>
- R. Khalaji, R. sarvar, A. R. A. F. (2010). Evaluation of issue 19 of national building regulation with SWOT model. *Sci J Geogr*, 13–32.
- Rahmani, O., Rezania, S., Beiranvand Pour, A., Aminpour, S. M., Soltani, M., Ghaderpour, Y., & Oryani, B. (2020). An overview of household energy consumption and carbon dioxide emissions in Iran. In *Processes* (Vol. 8, Issue 8). MDPI AG. <https://doi.org/10.3390/PR8080994>
- Raza, M. Y., & Lin, B. (2022). Analysis of Pakistan’s electricity generation and CO2 emissions: Based on decomposition and decoupling approach. *Journal of Cleaner Production*, 359. <https://doi.org/10.1016/j.jclepro.2022.132074>
- Rehman, A., Alam, M. M., Ozturk, I., Alvarado, R., Murshed, M., Işık, C., & Ma, H. (2023). Globalization and renewable energy use: how are they contributing to upsurge the CO2 emissions? A global perspective. *Environmental Science and Pollution Research*, 30(4), 9699–9712. <https://doi.org/10.1007/s11356-022-22775-6>
- Remuzgo, L., & Sarabia, J. M. (2015). International inequality in CO2 emissions: A new factorial decomposition based on Kaya factors. *Environmental Science and Policy*, 54, 15–24. <https://doi.org/10.1016/j.envsci.2015.05.020>
- Reuters. (2022, February). *As nuclear talks resume, Iran’s oil exports increase*. <https://www.reuters.com/business/energy/nuclear-talks-resume-irans-oil-exports-increase-2022-02-10/>
- Roodman, D. (2009). How to do xtabond2: An introduction to difference and system GMM in Stata. In *The Stata Journal* (Vol. 9, Issue 1).
- Salois, M. J. (2013). Regional changes in the distribution of foreign aid: An entropy approach. *Physica A: Statistical Mechanics and Its Applications*, 392(13), 2893–2902. <https://doi.org/10.1016/j.physa.2013.02.007>

- Sarak, H., & Satman, A. (2003). The degree-day method to estimate the residential heating natural gas consumption in Turkey: a case study. *Energy*, 28(9), 929–939. [https://doi.org/10.1016/S0360-5442\(03\)00035-5](https://doi.org/10.1016/S0360-5442(03)00035-5)
- Shao, X., Zhong, Y., Liu, W., & Li, R. Y. M. (2021). Modeling the effect of green technology innovation and renewable energy on carbon neutrality in N-11 countries? Evidence from advance panel estimations. *Journal of Environmental Management*, 296. <https://doi.org/10.1016/j.jenvman.2021.113189>
- Smil, V. (2020). *Energy Transitions: Fundamentals in Six Points*.
- Sodoudi, S., Noorian, A., Geb, M., & Reimer, E. (2010). Daily precipitation forecast of ECMWF verified over Iran. *Theoretical and Applied Climatology*, 99(1–2), 39–51. <https://doi.org/10.1007/s00704-009-0118-9>
- Soltani, M., Rahmani, O., Ghasimi, D. S. M., Ghaderpour, Y., Pour, A. B., Misnan, S. H., & Ngah, I. (2020). Impact of household demographic characteristics on energy conservation and carbon dioxide emission: Case from Mahabad city, Iran. *Energy*, 194, 116916. <https://doi.org/10.1016/J.ENERGY.2020.116916>
- Somosi, S., Kiss, G. D., & Md Tanvir Alam, S. (2024). Examination of carbon dioxide emissions and renewables in Southeast Asian countries based on a panel vector autoregressive model. *Journal of Cleaner Production*, 436. <https://doi.org/10.1016/j.jclepro.2023.140174>
- Suh, D. H. (2018). An entropy approach to regional differences in carbon dioxide emissions: Implications for ethanol usage. *Sustainability (Switzerland)*, 10(1). <https://doi.org/10.3390/su10010243>
- Sun, C., Chen, L., & Zhang, F. (2020). Exploring the trading embodied CO2 effect and low-carbon globalization from the international division perspective. *Environmental Impact Assessment Review*, 83. <https://doi.org/10.1016/j.eiar.2020.106414>
- Tang, B. J., Guo, Y. Y., Yu, B., & Harvey, L. D. D. (2021). Pathways for decarbonizing China's building sector under global warming thresholds. *Applied Energy*, 298. <https://doi.org/10.1016/j.apenergy.2021.117213>
- Tutberidze, g., Qetevan pipia, & Givi rakviashvili. (2018). the measuring of the Gini, Theil and Atkinson indices for Georgia republic and some other countries. *globalization and business*, 110–118. <https://doi.org/10.35945/gb.2018.05.016>
- United nations. (2015). *70/1. Transforming our world: the 2030 Agenda for Sustainable Development Transforming our world: the 2030 Agenda for Sustainable Development Preamble*.
- United Nations Environment Programme. (2021). *2021 GLOBAL STATUS REPORT FOR BUILDINGS AND CONSTRUCTION*. [www.globalabc.org](http://www.globalabc.org).

- U.S. Energy Information Administration. (2022a). *International Energy Statistics*.
- U.S. Energy Information Administration. (2022b). *Short-Term Energy Outlook*.
- Volodzkiene, L., & Streimikiene, D. (2023). Energy Inequality Indicators: A Comprehensive Review for Exploring Ways to Reduce Inequality. In *Energies* (Vol. 16, Issue 16). Multidisciplinary Digital Publishing Institute (MDPI). <https://doi.org/10.3390/en16166075>
- Wang, M., Hossain, M. R., Si Mohammed, K., Cifuentes-Faura, J., & Cai, X. (2023). Heterogenous Effects of Circular Economy, Green energy and Globalization on CO2 emissions: Policy based analysis for sustainable development. *Renewable Energy*, 211, 789–801. <https://doi.org/10.1016/j.renene.2023.05.033>
- Wang, Q., Fan, J., Kwan, M. P., Zhou, K., Shen, G., Li, N., Wu, B., & Lin, J. (2023). Examining energy inequality under the rapid residential energy transition in China through household surveys. *Nature Energy*, 8(3), 251–263. <https://doi.org/10.1038/s41560-023-01193-z>
- Wang, W., Tang, Q., & Gao, B. (2023). Exploration of CO2 emission reduction pathways: identification of influencing factors of CO2 emission and CO2 emission reduction potential of power industry. *Clean Technologies and Environmental Policy*, 25(5), 1589–1603. <https://doi.org/10.1007/s10098-022-02456-1>
- Wang, Y., Zhao, M., & Chen, W. (2018). Spatial effect of factors affecting household CO2 emissions at the provincial level in China: a geographically weighted regression model. *Carbon Management*, 9(2), 187–200. <https://doi.org/10.1080/17583004.2018.1451964>
- Wang, Y., & Zhao, T. (2018). Panel estimation for the impacts of residential characteristic factors on CO2 emissions from residential sector in China. *Atmospheric Pollution Research*, 9(4), 595–606. <https://doi.org/10.1016/J.APR.2017.12.010>
- Wang, Z., Li, Y., Cai, H., Yang, Y., & Wang, B. (2019). Regional difference and drivers in China's carbon emissions embodied in internal trade. *Energy Economics*, 83, 217–228. <https://doi.org/10.1016/j.eneco.2019.06.023>
- Welch, D., & Southerton, D. (2019). After Paris: transitions for sustainable consumption. *Sustainability: Science, Practice, and Policy*, 15(1), 31–44. <https://doi.org/10.1080/15487733.2018.1560861>
- Westerlund, J. (2007). Testing for Error Correction in Panel Data\*. *Oxford Bulletin of Economics and Statistics*, 69(6), 709–748. <https://doi.org/10.1111/J.1468-0084.2007.00477.X>

- Wolf, S., Teitge, J., Mielke, J., Schütze, F., & Jaeger, C. (2021). The European Green Deal — More Than Climate Neutrality. *Intereconomics*, 56(2), 99–107. <https://doi.org/10.1007/s10272-021-0963-z>
- Wooldridge, J. (2010). *Econometric analysis of cross section and panel data*. <https://books.google.com/books?hl=en&lr=&id=hSs3AgAAQBAJ&oi=fnd&pg=PP1&dq=Econometric+Analysis+of+Cross+Section+and+Panel+Data.+England+2002&ots=VYSWnwTVOv&sig=vgEyIcS5HCPJ9vuMX3U9PMzImPc>
- World Bank. (2019). *World development indicators*.
- Wu, S., Zheng, X., & Wei, C. (2017). Measurement of inequality using household energy consumption data in rural China. *Nature Energy*, 2(10), 795–803. <https://doi.org/10.1038/s41560-017-0003-1>
- Xiao, Y., Ma, T., Fang, Y. R., Huang, C., & Dai, H. (2024). Disparity and driving forces of energy consumption in China’s provincial urban residential sector under the carbon neutrality target. *Energy*, 131642. <https://doi.org/10.1016/j.energy.2024.131642>
- Xu, X., Tan, Y., Chen, S., Yang, G., & Su, W. (2015). Urban Household Carbon Emission and Contributing Factors in the Yangtze River Delta, China. *PLOS ONE*, 10(4), e0121604. <https://doi.org/10.1371/JOURNAL.PONE.0121604>
- Yang, J., Cai, W., Ma, M., Li, L., Liu, C., Ma, X., Li, L., & Chen, X. (2020). Driving forces of China’s CO<sub>2</sub> emissions from energy consumption based on Kaya-LMDI methods. *Science of The Total Environment*, 711, 134569. <https://doi.org/10.1016/J.SCITOTENV.2019.134569>
- Zhao, X., Ma, X., Chen, B., Shang, Y., & Song, M. (2022). Challenges toward carbon neutrality in China: Strategies and countermeasures. *Resources, Conservation and Recycling*, 176. <https://doi.org/10.1016/j.resconrec.2021.105959>