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Economic and Environmental Effects of Energy Transition in Iran by 2050: A Dynamic Multi-Regional Computable General Equilibrium Model

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Abstract

Iran relies on fossil fuels for its energy supply, which has led to economic and environmental challenges. In recent years, imbalances in energy production and supply have caused significant damage to various economic sectors. Therefore, paying attention to the composition of the portfolio of energy and the impact of the energy transformation process in this country is very important. Accordingly, this research aims to examine the economic and environmental effects of energy transition in Iran with its energy trading partners. To this end, three scenarios for changing the composition of energy portfolios in Iran's energy transition process were analyzed using a computable multi-regional general equilibrium model. The results of this study indicate that increasing the share of electricity generated from renewable energy sources while keeping non-renewable electricity production constant has positive economic effects and reduces carbon emissions. Also, applying the scenario of increasing renewable energy while reducing energy produced from fossil fuels showed that welfare and GDP decreased by 3.17 and 2.37 percent, respectively, and also that carbon emissions decreased by 10.89 percent in this scenario, which was a greater decrease than in previous scenarios. Therefore, the reduction in fossil fuel energy production should occur at a gentler rate compared to the increase in renewable energy production.

Highlights

- This study uses a general equilibrium model to be calculated to check the economic and environmental impacts of the energy conversion process in Iran.
- Three scenarios examine the effects of increasing renewable energy and reducing fossil fuels in different scenarios.
- In the first and second scenarios, there are positive economic and environmental consequences, and in the third scenario, only positive environmental effects are visible.

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1. Introduction

Today, the development and production of renewable energy have become one of the main priorities of national policies due to environmental concerns, the fear of depletion of fossil fuel resources, and the importance of diversifying energy sources. The proportion of renewable sources in global energy production has increased significantly in recent years, nearly double from 2007 to 2021, reaching 28% (Statista, 2021).It is predicted that by 2040, the share of renewable energy in the overall energy mix will rise to 45%, with the most attention being directed toward wind, solar, and hydropower (Renewable energy C2ES, 2021). The limitations of fossil fuel resources and global warming caused by greenhouse gas emissions have confronted policymakers and planners with new and changing economic realities. As a result, economic strategies that relied on the unlimited and cheap supply of fossil fuel resources can no longer continue as they did in the past for an extended period. The interplay of factors such as increased energy consumption, rising energy prices, growing resource constraints, climate change, and the declining capacity of ecosystems to provide vital services has led to increased vulnerability and environmental, economic, and social uncertainties (Panahi & porasghar, 2015).

The connection between energy, economic issues, and environmental issues in the world, and especially in our country, has led to a change in approach towards a green economy. According to the United Nations definition, a green economy is a model that leads to increased human well-being and social equality while reducing environmental risks. Green economy is a type of economy in which economic growth and development is based on the ecological equilibrium of the environment, so the two goals of economic development and environmental protection can be implemented simultaneously. The increase in the use of renewable energy, in addition to the advantages of reducing greenhouse gas emissions, reducing the risk of price increase of fossil fuel. Renewable energy sources have a long life and natural cycle, and unlike fossil fuels, they are not exhausted, ensuring the continuity of energy consumption for future generations (Salimi et al, 2023)

As a country dependent on fossil fuels, Iran has a significant share in energy consumption and pollutants emissions. Statistics show that over 98% of Iran's energy consumption is supplied through these resources, which has led to numerous problems, such as air pollution and the complications caused by it (Tavana et al., 2019). Based on available statistics, Iran's per capita energy consumption is very high, and the country is among the top 15 energy-consuming nations globally, with energy consumption rising from 3,322 TWh in 2021 to 3,531 TWh in 2023. International statistics indicate that Iran, with a 1.86% share of global greenhouse gas emissions in 2022, is among the top 10 polluting countries in the world (Global Carbon Budget, 2023).

Under the Paris Agreement, Iran has committed to reducing its carbon emissions by 4% to 12% compared to the 2010 baseline level between 2020 and 2030. It is worth noting that achieving the 12% reduction scenario depends on lifting unjust sanctions against Iran and providing engineering and economic assistance to the country (Parliamentary Research Center, 2016). According to a report by Berkeley Earth, Iran's temperature has increased by 2 degrees Celsius in 2020.Predictions indicate that if the current trend continues, Iran's temperature will reach approximately 4°C by the end of 2100 (IPCC, 2021). Therefore, to address the serious consequences of climate change, including rising temperatures in Iran, it is essential to take practical actions to fulfill Iran's commitments under the Paris Agreement.

Statistics on electricity production in Iran by energy source for 2021 show that 94% of electricity is generated from fossil fuels, while nuclear energy accounts for 1%, renewable energy for 0.5%, hydropower for 4.3%, and other sources for 0.2% (Chart 1). These statistics highlight the high volume of fossil fuel consumption in the country, which serves as a warning sign for the future of the country's environment and the sustainability of its electricity production.

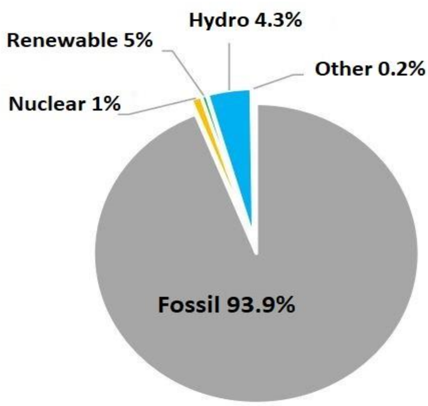

Figure 1. Electricity production in Iran by energy source for 2021.
Source: *bp Statistical Review of World Energy 2022*

On the other hand, the Seventh Development Plan Law, approved in 2024, has set a target of reaching a nominal capacity of 124,000 megawatts. Of this amount, 12,000 megawatts are allocated to renewable power plants, and 3,000 megawatts are allocated to nuclear power plants. In other words, To achieve the goals of the seventh development plan, more than 40% of the capacity of new power plants must be allocated to non -fuel power plants. Achieving the goals of the Seventh Development Plan in this area will, to some extent, impact the diversification of the country's electricity generation portfolio (Figure 2).

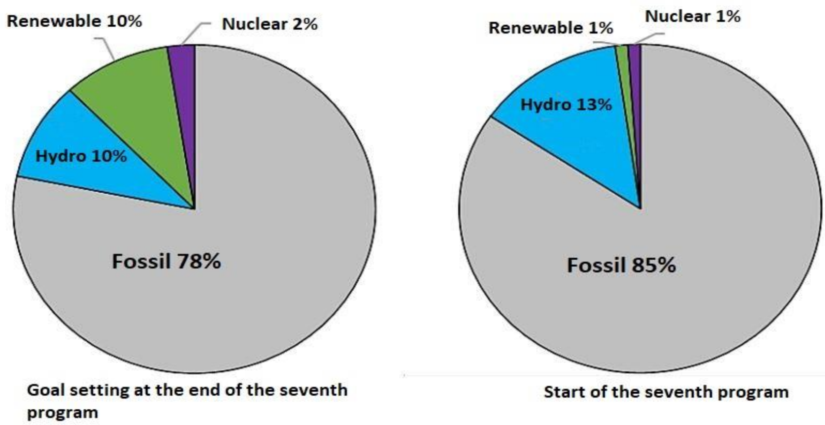

Figure 2. Status of the Country's Electricity Generation Portfolio in the Seventh Development Plan.

Source: *Report by the Research Center of the Islamic Consultative Assembly, 2024*

Given the current state of energy production sources and the policies outlined in the Seventh Development Plan, securing sustainable energy as one of the essential inputs for electricity generation is an unavoidable necessity for supporting sustainable development in Iran. The limited availability of fossil fuel resources in Iran, the need to absorb and mitigate pollutants resulting from the consumption and combustion of fossil fuels, the continuous changes in production technologies, and the national and international obligations related to fossil fuel consumption have driven the global community to seek the expansion of renewable and sustainable energy sources to meet their needs. Therefore, paying attention to the energy transition in Iran, as well as understanding the economic and environmental consequences of this transition, is of great importance. Luckily, most nations within the world have realized the significance and part of different vitality sources, particularly renewable energies, in assembly current and future needs (Mousavi et al., 2016), so that currently renewable energies have replaced the mainstream of the electricity industry, and among their various types, wind power, solar power, and photovoltaics are leading the market. The share of renewable energies (hydro, wind, sun based, tidal and geothermal) of introduced control plants in OECD nations is approximately 32.4%.Therefore, given the importance of the issue and the importance of providing sustainable energy in the country, the present study contributes to the existing literature on energy transition in two areas: He first considered the economic impacts of the energy transformation process as well as the policies of the seventh development plan, and then examines the environmental impacts simultaneously alongside the economic impacts. One of the distinguishing points of the present research is the examination of energy transition policies and their effects in a multi-regional context. The method used in this project uses a general equilibrium model (CGE) to calculate regional diversity (CGE). Cge models are models of macroeconomic policy simulation models that can predict the effects of the economy of external shocks and / or political interventions. With a specific reference for this project, dynamic CGE models have additional advantages to create deeper analysis of the adjustment trajectory of any long -term energy planning script. This research addresses the question: *What economics and environmental consequences will the energy transition process in Iran entail?* To answer this question, following this introduction, Section 2 provides a literature review focusing on empirical studies related to energy transition and the history of energy transition in Iran. Section 3 examines the research background. Subsequently, Section 4 highlights the model specifications, Part 5 Presenting the results obtained and part 6 draw conclusions and political recommendations.

2. Theoretical Foundations

This section reviews the theoretical literature in two parts. First, it examines the latest studies in the field of energy transition, followed by an exploration of the history of energy transition and the most significant events in the country's renewable energy sector.

2.1 Energy Transition

It has been proposed that the process of energy conversion related to changes in the composition of energy production, distribution and consumption models? To prevent or minimize? Greenhouse emissions (Repsol, 2024). The energy transformation not only to meet the challenges of climate change, but also bring opportunities for a more sustainable, resilient and prosperous future. Energy conversion can be defined as a significant change in the energy system of a country, an area or even on a global scale. This change may be linked to the system's structure, Its energy sources, its cost (economy and non -economic), or even political and economic models in which energy is provided and consumed (Linares, 2018).

Current documents on energy transformation are often focused on exploring the specific technologies for resources such as oil, coal or gas (Hirsh & Jones, 2014) with renewable energy sources (RES), such as solar, wind and energy storage technology (Lazaro, 2023). However, Serrani (2020) noted that in the 1990s, the political discourse of many regional governments included environmental concerns and pressure to achieve economic growth and poverty reduction, leading to policies to ignore environmental sustainability. This emphasizes the conflict between economic development and environmental sustainability, more serious by the dependence on the export of raw materials and the unofficial labor market to increase social inequality. Studies of Hirsh & Jones (2014) and Sovacool (2016) showed that the energy transformation document has focused on replacing specific sources or fuel technology, such as oil, coal or gas.

Scholten's book (2018) considers the geopolitical meaning of the conversion process to renewable energy and is the most suitable job in energy conversion.

The book refers to different topics, including the winner and the loser in the global energy scenario, changes in regional and bilateral energy relations between existing powers and emerging powers, government reactions to infrastructure development and transition. The author realized that the future geopolitical landscape of energy will be a blend of renewable and common energy sources.

Hache (2018), by checking global effects on renewable energy expansion, argues that new challenges due to energy transformation policies can increase the complexity of current energy geography. Local and decentralized relations can add a new geopolitical layer to traditional agents, while technical, economic, social, behavioral and legal aspects can complicate emerging puzzles. A significant increase in the ratio of renewable energy in the world's energy mixture can lead to interdependence and surprise, especially dependence on rare and important materials and new diplomatic formation in renewable energy.

Gielen et al. (2019) Check the technical and economic characteristics of the fast energy conversion process by 2050 and confirm that the efficiency of energy and renewable energy technology is the main factor of this conversion process. Their analysis shows that the decoding of profitable energy systems because it creates new jobs (about 19 million directly and indirectly additional jobs by 2050), compensating for losing about 7 million jobs. Therefore, the global energy transformation process leads to 11.6 million direct and indirect work in the field of energy.

Dellafield et al. (2021) Presenting the framework of Energy Scenario (ESE), which can be used to assess the impact of the energy script on society and the natural environment. This concept frame uses interdisciplinary and quantitative methods to determine whether an energy scenario may lead to an acceptable and long -term energy transformation. SDG shows how energy transformation is associated with human development and the importance of integrating environmental and socio -economic data into energy models to design energy scenarios to meet other political priorities.

The energy conversion will have a significant impact on the current energy system, with changes in planning and operational paradigms, market structures, and regulatory frameworks (Berjawi et al., 2021). Although the goal of switching to a more sustainable energy system can be clear, the development and implementation of tools and conditions to achieve it is a very complex task. This complexity is the result of a number of factors, including technological advances, political frameworks, economic considerations, social behaviors and environmental impacts. The implementation of a sustainable energy system requires planning, innovation, cooperation and meticulous adaptability to overcome different challenges and uncertainties.

From the perspective of research and development, energy efficiency and conversion to renewable energy are the main actions (Aunedi et al., 2020), In addition to the technological process (Rusu, 2022), the development of infrastructure (Nielsen et al., 2023) and political support (Lund et al., 2022).

Fernández (2024) comprehensively evaluates energy transition roadmaps, legal measures, policies, and government initiatives to achieve net-zero emissions. This study emphasized the central role of cooperation between civil society, government organizations, private sectors and international partners in implementing a cleaner energy system. It shows that if the energy conversion benefits from support policies, economic incentives and technological advances, challenges such as financial obstacles, public participation and the prescribed gap must be resolved. To clarify zero emissions, proposed political meanings include economic changes to renewable energy, urban practice and financial advantages for environmental advantages, enhance forest conservation, invest in energy storage and network infrastructure, optimize cross -energy planning, concentration of biological logistics, biological logistics, energy efficiency, energy projection of the training stations of the traces CCU.

Castro (2024) introduces and proves the application of large renewable energy as an essential part of the energy transformation process, replacing fossil fuels. This replacement is clear in electrical systems, but the introduction to other areas, such as shipping, will be essential, by combining renewable energy sources in facilities such as vehicle service centers or gas transport technology. The introduction of electricity in a country implies a group of technologies necessary to implement it, such as electric cars, charging stations and maintenance seminars for this technology.

2.2 History of Renewable Energy Transition

The global transformation in the energy sector has intensified in recent decades, especially since the 2010s, with a focus on reducing dependence on fossil fuels and developing renewable energies. Studies show that this transition has included a decrease in the share of hydrocarbons in energy consumption, increased investment in new renewable energy capacities, and growing demand for clean energy sources in countries such as China and South Asia (Prokofev, 2024). Comparative studies in Spain and Chile have shown that diverse strategies and policies have led to different results in economic and social indicators (Maskalenko & Medvedev, 2024). In India, the growth of the solar energy industry has accelerated with the reduction in the cost of installing solar panels and government support (Kosareva, 2024). Also, in Latin America, especially in Brazil, investment in bioenergy and renewable energies has continued since the 1970s, but dependence on fossil fuels remains high (Rodrigues & Costa, 2024). In the climate justice dimension, there is an emphasis on the need for a rapid transition to clean technologies and social transformation to address environmental crises (Assis et al., 2024).

2.2.1 Pre-1990s

During this period, no significant or remarkable developments in renewable energy were observed in Iran. The high global prices of fossil fuels and the abundant reserves of these fuels in Iran did not act as strong incentives for adopting new energy technologies. At the time, officials focused primarily on developing gas and steam power plants. Given the relatively high population growth and the sharp increase in electricity consumption, there was a pressing need to expand electricity production rapidly. Iran's only reliable and sufficient resource was its natural gas reserves, which led to the development of gas power plants. Activities related to renewable energy in Iran began seriously in the early 1990s. However, the use of windmills and wind catchers in Yazd has been daily in the country for many years (Mousavi Dorcheh et al,2018).

2.2.2 The 1990s

During this decade, similar to previous periods, significant growth in renewable energy was observed in various countries, particularly in European and some Asian nations. This trend led to the involvement of several domestic experts and policymakers in this field. Additionally, this period saw the further strengthening of fossil fuel and large hydropower plants in Iran. The development and production of gas and combined-cycle power plants progressed at an accelerated pace. In renewable energy, the first Iranian solar panels were produced in the early 1990s by Fiber Optics and Solar Cells, established in Tehran in 1989. The Renewable Energy Organization of Iran (SUNA) was established in 1995 as a non-governmental organization affiliated with the Ministry of Energy, responsible for overseeing renewable energy initiatives. In 2000, Iran's atomic energy organization signed a contract with SDEeed private company to install 90 MW wind turbines in Manjil, Gilan province. One of the most important events of the 2000s was the approval of Article 62 of the Law on the Regulation of Part of the Country's Financial Regulations (Mousavi Dorcheh et al, 2018).

2.2.3 From 2005 to 2012

The only significant event in the renewable energy sector during this period was the approval of the Subsidies Reform? Law in Iran. On December 18, 2010, the official implementation of this law was announced. According to this law, the energy sector was subject to the elimination of subsidies and the supply of energy at international prices. Over five years, subsidies for energy products including gasoline, diesel, gas, oil, electricity, and water were removed, and these goods were supplied at prices comparable to those in the Persian Gulf markets. In late 1999, the Supreme Administrative Council, based on a parliamentary resolution in December 2004, transferred all legal activities related to renewable energy, including those of the Atomic Energy Organization, the Ministry of Agriculture, and the Fuel Consumption Optimization Organization, to the Ministry of Energy. Subsequently, in March 2004, the Ministry of Energy transferred this responsibility to the Renewable Energy Organization of Iran (SUNA). In 2005, SUNA began supplying and installing 260 kW turbines. One of the significant events in the solar energy sector in 2007 was the launch of a project to electrify remote villages without access to the power grid. This project aimed to provide electricity to these areas. In July 1999, the Renewable Energy Technology

Development Headquarters was established to commercialize research results and serve as a key link in the renewable energy innovation chain. Additionally, in 2011, the Wind Energy Scientific Association and the Renewable Energy Research Institute were established. In the fifth economic, social and cultural development plan of the five years of the Iranian Islamic Republic, the government announced, based on Article 139, that it was authorized to support the private and cooperative sectors through managed? funds and interest subsidies to facilitate the production of up to 50 MW of wind and solar energy (Mousavi Dorcheh et al,2018).

2.2.4 From 2012 to the Present

The most significant events during this period include:

- The Iran Nuclear Deal (JCPOA): Iran's agreements with 105 countries under the JCPOA opened political and economic spaces and increased trade and industrial interactions with industrialized countries. The Joint Comprehensive Plan of Action (JCPOA) was signed on July 14, 2015, in Vienna between Iran and the P5+1 group (China, France, Russia, the UK, the US, and Germany). Based on this agreement, many international economic, trade, and industrial sanctions were lifted. Two years after the implementation of the JCPOA, the volume of foreign investment demand in Iran's renewable energy sector, particularly solar and wind energy, reached $4 billion.
- Approval and Implementation of the Law on Subsidizing Electricity Purchases from Renewable Sources.
- Iran's Commitment to the Paris Climate Agreement (COP21) and the Reduction of Greenhouse Gas Emissions by 4-12%.

In 2013, Article 62 of the annual government budget law allocated a specific credit line to receive 30 Rials[1] per kilowatt-hour as electricity tariffs for purchasing renewable electricity. Additionally, a permission was issued to conclude contracts using the buyback method with private and public sector investors, prioritizing domestically produced equipment. In 2015, the Renewable Energy Support Association was established. Finally, in 2016, despite the importance of clean energy, after the merger of the Iran Energy Efficiency Organization and the Renewable Energy Organization of Iran, the Renewable Energy and Energy Efficiency Organization (SATBA) was established. The formation of this organization dates back to Article 8 of the Law on Modifying Consumption Patterns. In the Sixth Development Plan, the share of renewable energy in the country's energy portfolio was set at 5,000 MW.

The development of various renewable energy applications in the country can provide many advantages, including increased energy security, reducing the impact of climate change, stimulating economic growth, creating jobs, increasing per capita income, social equality and environmental protection in all fields. With

[1] $0.001 per kWh

these advantages and the country's management of non -petroleum economy, it is essential to prioritize the development of renewable energy. In addition, the development of renewable energy is linked to global orientation and upstream programs of the Iranian Islamic Republic in the field of energy. For example, according to the Vision Document, by 2025, 10% of the country's electricity demand should be met from renewable sources (Mousavi Dorcheh et al, 2018).

3. Research Background

Many studies have been conducted on fuel conversion and fossils with renewable energy in Iran and other countries around the world. Many researchers discovered its renewable energy and potential in Iran, while others focused on policies and impacts of energy transformation in specific areas of the Iranian economy. Below, we consider some recent studies in this field.

Tavakoli et al. (2013) evaluated energy resources in Iran with a focus on the green economy. The study examined how the green economy can utilize Iran's potential. The results indicate that Iran can move toward sustainable development and a green economy by relying on existing potential and concentrating investments in renewable energy, thereby reducing its heavy dependence on fossil fuels.

Using an autoregressive model, Tahami Pour & Abedi (2016) studied the impact of clean energy on real economic growth per capita in Iran from 1967 to 2012. The results showed that the negative relationship between real economic growth per citizen and renewable energy consumption, fuel, recycling materials and short -term electricity energy. Long -term results also show significant negative relationships between electricity consumption, renewable energy, fuel and recycled materials and real economic growth per capita.

In his research, Sadeghi (2015) explored optimizing energy resource supply to produce and develop renewable energy by 2025 in Iran. He concluded that meeting electricity demand could help reduce environmental pollution. The study proposed a robust optimization model for the long-term horizon of 2025 by minimizing the cost function and considering three constraints: resources, demand, and technical limitations. The results suggest that 15% of electricity production by 2025 should come from solar energy.

Mohammadi & Danaeefard (2019) presented a model for participatory governance in developing renewable energy in Iran. They highlighted governmental barriers, including the need for incentive and guarantee laws, and institutional, normative, and cognitive obstacles, such as conflicting interests, lack of commitment from policymakers, and insufficient private sector trust. They proposed solutions such as using commitment tools like campaigns, coalitions, and associations, involving government institutions in financing and social benefits, realigning energy carrier prices, and employing a mix of demand- and supply-side policies.

Ghasemi & Khalili (2020) have used a dynamic approach to systems to check Iran's energy targets. According to these goals, Iran aims to provide 10% of electricity from renewable sources by 2025, as stated in a 20 -year vision document. The results showed that only 38% of the fourth development plan programs to build renewable power plants were implemented.

Ahmadinia et al. (2021) studied the impact of global energy transformation on maritime security in Persian Gulf. The main research question was: *"Under what conditions can the global energy transition transform maritime security in the Persian Gulf?"* The preliminary answer is that *"only if the geo-economic cooperation of Gulf Arab countries and China escalates to the level of military and security cooperation can the global energy transition change the pattern of maritime security in the Persian Gulf."* The conceptual framework of this study is based on the geopolitics of energy transition. The findings, obtained through inferential methodology, confirm the hypothesis and suggest that while geo-economics changes may accompany geopolitics changes, realizing these changes in the absence of strategic and military developments could take several decades.

In a study examining the relationship between clean energy, domestic and foreign capital development, economic growth, and environmental quality in a group of developing countries from 1995 to 2012, Daei Karim Rad et al. (2021) found that clean energy projects in these countries have lower returns and require more financing compared to other energy supply projects. Due to the underdevelopment of financial institutions and limited access to necessary funding, there is little incentive to invest in clean energy projects, hindering carbon dioxide reduction.

Esmaeili Ardakani & Shokri (2023) explored the global and regional economic shifts toward renewable and clean energy. They sought to outline Iran's role in the future of the evolving energy system. The study's main question was: *"What role will Iran play in the geopolitical landscape of the global energy economy by 2050, as clean fuels become the main drivers of the global economy?"* The study, conducted using qualitative methods and scenario writing, collected data through interviews and expert panel surveys. The results were presented in four probable scenarios: *"Achieving Sustainable Development and Transition to Green Gold,"* *"Gradual and Independent Transition to Sustainable Development and Green Gold,"* *"Development Based on Black Gold,"* and *"Development Stagnation with Black Gold."* These scenarios cover many possible situations, helping policymakers and stakeholders consider various options in renewable energy policy-making.

In a study based on SWOT analysis, Salimi et al. (2023) examined renewable energy's strengths, weaknesses, opportunities, and threats. They proposed strategies for renewable energy development, including strengthening private and public sector activities for investment in energy production, conducting research projects to reduce greenhouse gases, investing in technology development for renewable energy utilization, promoting renewable energy for low-cost energy extraction, enhancing the energy stock market, and investing in the localization of equipment needed for renewable energy utilization.

In 2016, Loisair et al., In an article entitled a green economy and related concepts, an overview of the definitions of the green economy and related concepts and evaluating these concepts. As part of the green economy, there are many different levels of alternative and compromise between environmental and economic advantages, and a structural change in human lifestyle is necessary. In this study, by discussing the concept of green economy, approaches and related tools, he tried to contribute to their definitions and relationships as a previous condition for the operation of the green economy.

Gross and Ghaffar (2019) emphasized the gradual decline in the role of fossil fuel and the importance of energy resources in the region. They emphasized the need for economic diversification and sustainable income sources in the Persian Gulf countries. While their concerns about the economic security of the Persian Gulf countries in the face of energy transition are noteworthy, the evidence and arguments presented suggest that the impact of this phenomenon in the Persian Gulf is more focused on oil transportation than production. Thus, the energy transition affects the region's security order more than the oil revenues of the Persian Gulf countries.

Hang (2020), It is recognized that Australia only supplies 6 percent of its energy from renewable sources and 86.3 percent of its electricity comes from fossil fuels. But with the closure of coal-fired power plants and commitments to reduce emissions, the country is transitioning to renewable energy, and there is evidence of progress in this area.

In a study examining energy transition in South Africa post-COVID-19, Bohlmann et al (2023) has used a dynamic model of dynamic area (CGE) to analyze the effects of the economic scale of various political scenarios related to changes in electricity production, investment costs and international action costs for incompatible industries. The research concentrated on at-risk sectors and demographic groups in Mpumalanga. Main findings reveal that (1) Mpumalanga's economic framework will be influenced in the medium to long term irrespective of the domestic transition strategy (2) Mpumalanga's economy may decline compared to the baseline unless a just energy transition (JET) is executed swiftly and thoughtfully, and (3) nationally, there is an opportunity for dual advantages when making South Africa's economy greener, with anticipated enhancements in both economic growth and environmental results over the long term.

Belgacem et al (2023) investigated the impact of green bond financing on boosting environmentally conscious investments in anticipation of the low-carbon energy transition within emerging Asian economies. The outcome indicated that every one of these factors plays a significant role in environmental investment. Furthermore, the findings indicated that the impacts of global warming can be mitigated through green bonds to facilitate the ideal shift to low-carbon energy.

Ghisellini et al. (2023) evaluated the environmental impacts of some "cleaner electricity" scenarios during the period of energy transformation and circulating economy in Italy and Europe. Using a life cycle assessment (LCA) approach, the study assessed the environmental impacts of electricity in Italy and the EU under various government and research scenarios. The findings indicate that transitioning from the business-as-usual (BAU) electricity mix (2021) to the government's emergency strategy (2021-2023), which substitutes 14% of Russian natural gas with 42% oil and coal along with 58% renewables, marginally lessens midpoint impacts. The global warming potential diminishes in alternative modeled scenarios, where the use of natural gas is projected to decrease from 30% to 60% in support of renewables (government plan 2030 scenario). Nonetheless, additional effects, primarily on land and human health, are anticipated to deteriorate, emphasizing the necessity for major advancements in renewable energy technologies.

Oshiro et al. (2023) investigated a different yet expensive energy transition scenario that incorporates carbon capture and utilization (CCU), potentially maintaining current energy demand technologies. They employed a global energy system model to examine a net-zero emissions scenario centered on CCU. They discovered that synthetic fuels might satisfy 30% of energy needs by 2050, maintaining certain current technologies in demand sectors. Nevertheless, this situation necessitates swift expansion of non-biomass renewable sources and direct air capture technology. Although the CCU-based scenario presents an alternative route, it comes with several challenges concerning technological viability and higher mitigation expenses when compared to net-zero scenarios that utilize renewables, bioenergy, and carbon dioxide removal.

Chang et al. (2023) examined imaginative energy approaches for carbon reduction, developing scenarios for energy transition in Chile by 2050. Using the Energy PLAN model to simulate hourly energy system performance, the study demonstrated that transitioning Chile's energy system to 100% renewables is technically more efficient than current national scenarios while aligning with climate neutrality goals. The examination also emphasized that particular alternatives might be prioritized at various phases of the energy transition, reflecting a better balance between carbon reduction and expenses.

Gonocruz et al. (2024) evaluated multiple scenarios for energy transition mechanisms in the Philippines toward decarburization. The research suggested enhancing renewable energy options like wind and solar. The analysis demonstrated that by optimizing the electricity supply mix, coal consumption could be decreased by 37.23%. Solar energy may represent 20.07% of overall energy use, while wind energy could make up 8.83%, excluding battery energy storage systems (BESS). Through the implementation of BESS and the enhanced use of solar and wind energy in accordance with the nation's 2030 goal, coal consumption might decrease by 30.44%.

Murshed, M. (2024), to check the transformation of renewable energy can grow green? The role of good management in promoting economic growth is adjusted according to carbon emissions in the next eleven countries. The results obtained from economic analysis approved that renewable energy conversion only promotes green growth if the quality of management in the next eleven countries is improved in parallel.

By examining the studies conducted in the field of energy transition, especially for Iran, we see that most of the studies have examined the potential of renewable energy capacity in the country as well as the effects of energy transition on the country's economic growth. The present research is innovative in several ways: 1- Comprehensive study of the effects of energy transition in both the economic and environmental spheres. 2- Using a multi-regional general equilibrium model to study the effects of energy transition. 3- Regionalization of the research based on Iran's most important trading partners in the field of electricity exports and imports. 4- Forecasting the effects of energy transition by 2050 in line with climate conferences.

4. Modeling

4.1 CGE Model

The standard model is static (single-period) or involves one or more countries with fixed factors of production. The GTAP (Global Trade Analysis Project) model is a multi-regional, static model with a Version 10 database, including a social accounting matrix for 161 countries and 76 sectors. The GTAP model's theoretical foundation is similar to other multi-regional CGE models. The system of equations of this model includes two types of equations: accounting relationships, ensuring that the income and cost of each economic agent are equilibrium equations and behaviors, based on micro -economic theory and describing the optimization behavior of agents such as companies and consumers (Brockmeier, 2001). Hertel presented this model (1997). The model used in this study is a multi -regional model for Iran and its energy trading partners.

The GTAP-E model, an extension of GTAP, was designed to analyze the effects of international climate change policies. The difference between this model and Hertel's model lies in the addition of a composite capital-energy input to the production structure and the inclusion of carbon emissions from fossil fuel combustion as an input in the production process of region *r* or as an output from the consumption of goods by private and public households (Truong & Burniaux, 2002; Nijkamp et al., 2005). The electricity sector in the GTAP-E model is replaced by a virtual commodity called "electricity" in the GTAP-E-Power model, which combines transmission, distribution, nuclear energy, coal, gas consumption for electricity production during peak and off-peak hours, oil consumption during peak and off-peak hours, hydropower during peak and off-peak hours, wind energy, solar energy, and other electricity generation technologies (Peters, 2016).

The GTAP-E-Power model, developed by Peters (2016a), is used to develop new carbon markets and includes non-CO2 emission accounts, forming the GTAP-E-Powers model. This model comprises four economic agents: producers, households, governments, and the international sector. Overall, the GTAP-E-Powers model retains the production and consumption structures of GTAP-E-Power. Given that the main focus of this study is to examine the shift from fossil fuel consumption to renewable energy, particularly in electricity production, it is necessary to explain the behavioral equations of firms related to energy and electricity layers separately in the GTAP-E-Powers model. These layers are discussed below.

Since the research scenarios involve the transition from non-renewable to renewable energy, the model requires changes in the share of renewable electricity production. Finally, the business behavior works in different production classes are presented and distinguished among different types of energy. In each production class, the functions required the condition of the items are taken on the principle of cost reduction, in which the target function is the cost and binding is the company's production technology. Production technology according to constant elasticity of the alternative structure (CES). It should be noted that in certain layers, such as the total production layer, the elasticity of the replacement is no, which means that this function becomes a function of Leontief . In general, the target and stress functions in each class are as follows:

$$\text{Min } \sum_e P_e Z_e \qquad st: \quad Q = \alpha\left(\sum_e \theta_e Z_e^{\frac{\sigma-1}{\sigma}}\right)^{\frac{\sigma}{\sigma-1}} \qquad \sigma = \frac{1}{1+\rho} \tag{1}$$

In the equation, Z_e ،P_e ،Q ،θ_e ،σ ،α و $\rho$and e represents the e input, the price of the e input, the level of production, the distribution parameter, Elasticity of replacement, effective parameters and distribution parameters, respectively. Conditional requirements for electronic inputs are taken from the resolution of the above optimization problem and are expressed as follows:

$$Z_e = Q\left(\frac{\theta_e C_Q}{P_e}\right)^{\sigma} \alpha^{\sigma-1} \tag{2}$$

C_Q The function represents the average cost function, regardless of the level of production. Therefore, it can be concluded that the cost function is an increasing and linear uniform function of the level of production.

$$C_Q = \frac{\sum_e P_e Z_e}{Q} = \frac{\left(\sum \theta_e{}^{\sigma} P_e{}^{1-\sigma}\right)^{1/_{1-\sigma}}}{\alpha} \tag{3}$$

In the equation 4, the demand functions are expressed in linear functions according to the growth rate of the variables. It is worth noting that the dot notation above the variables indicates the growth rate of the variables.

$$\dot{C}_Q = \sum_e \beta_e \left(\frac{\dot{\theta}_\iota}{\rho} + \dot{P}_e\right) - \dot{\alpha} \qquad \beta_e = \frac{P_e Z_e}{\sum_m P_m Z_m} \tag{4}$$

$$\dot{Z}_e = \dot{Q} + \sigma\left(\dot{\theta}_e + \dot{C}_Q - \dot{P}_e\right) + (\sigma - 1)\dot{\alpha} \tag{5}$$

Various elements affect the demand for inputs, which can be categorized into four primary groups:

Scale Effect ($\dot{Q}$): This indicates how alterations in production affect the need for inputs.

Substitution Effect $\sigma\left(\dot{C}_Q - \dot{P}_e\right)$: This shows the effect of changes in relative prices. The relative price increase of inputs will reduce its demand while increasing the demand for other inputs.

Effect of Technical Changes in Inputs on Demand ($\sigma\left(\dot{\theta}_e\right)$: The productivity improvements of the items that have a vague influence on their needs, depending on the elasticity of the replacement between the inputs. The higher the elasticity of the replacement, the higher the ability to increase the demand for contribution.

Effect of Hicks's neutral technology growth or the growth of total productivity (TFP) $(\sigma - 1)\dot{\alpha}$): This represents the impact of neutral technological changes or overall productivity growth on input demand.

The correspondence can be established between the relationships described above and the behavioral equations of companies in the GTAP-E-Power model. More specifically, the behavioral methods for all production layers can be sourced according to the above relationships. For total production classes, words can be set as follows:

Table 1: Correspondence between Variables and Parameters in Value-Added, Energy, and Total Production Layers

The suitability between variables and parameters within the total output		The suitability between variables and value added parameters and energy groups	
$qf_{emn} = \dot{Z}_\iota = Q\dot{F}_{emn}$	Demand for *e* for use in sector *m* in region n (%)	$qf_{emn} = \dot{Z}_e$	Demand for e for use in m in region n (%)
$pf_{emn} = \dot{P}_e = P\dot{F}_{emn}$	price of input e by firms in m of region n (%)	$pf_{emn} = \dot{P}_e$	price of input e by firms in m of n (%)
$qo_{mn} = \dot{Q} = Q\dot{O}_{mn}$	quantity of output m in region n (%)	$af_{emn} = \frac{\sigma_{mn}}{\sigma_{mn} - 1}\dot{\theta}_{emn}$	biased technical change of input e in m in region n (%)
$ps_{mn} = \dot{C}_Q$	Cost price of goods e in region n (%)	$, qf_{"vaen"mn} = \dot{Q}$	Demand for a composite of added value and energy
$af_{emn} = \frac{\sigma}{\sigma - 1}\dot{\theta}_{emn} = -\frac{\dot{\theta}_{emn}}{\rho}$	biased technical change of input e in sector m in region n (%)	$\dot{\alpha} = 0$	TFP change is zero in this nest and others
$ao_{mn} = \dot{\alpha}$	Hicks neutral technological change(%)	$pf_{"vaen"mn} = \dot{C}_Q = P\dot{F}_{"vaen"mn}$	Combined cost of added value and energy
$ESIV_{mn} = \sigma_{mn}$	Substitutability elasticity between intermediate goods and value added	$EVA_{mn} = \sigma_{mn}$	Elasticity of substitution among inputs in the value-added and energy nest

Source: *Shahbaz et al (2024)*

The linear and nonlinear varieties of conditional demand functions, as well as composite price indices, are showcased at various levels of production technology. According to the cost reduction principle in the overall production layer, the combined demand for value-added and intermediate goods is established. (Equations 6, 7, and 8). It should be noted that the demand functions in Equations 6 and 7 are the linear forms of Equation 5.

4.2 Total Production Layer

$$QF_{emn} = QO_{en} AO_{en}^{ESIV_{mn}-1} \left(\frac{PF_{emn}}{\dot{\theta}_{emn} PS_{mn}}\right)^{-ESIV_{mn}} \quad (6)$$

$$qf_{emn} = qo_{mn} + ESIV_{mn}\left(\theta_{emn} + ps_{mn} - pf_{emn}\right) + (ESIV_{mn} - 1)ao_{mn} \quad (7)$$

$$qf_{emn} = qo_{mn} - ao_{mn} - af_{emn} + ESIV_{mn}(ao_{mn} + af_{emn} + ps_{mn} - pf_{emn}) \quad (8)$$

The need for the capital-energy combination is established in the second level of the technology tree (Equations 9, 10, and 11). In the GTAP-E-POWER model, energy inputs are incorporated into the value-added layer to facilitate the replacement of capital with energy. Specifically, $QF_{"vaen"mn}$ and $PF_{"vaen"mn}$ the composite demand and price of the value-added-energy bundle, respectively.

4.3 Value-Added-Energy Layer

$$QF_{emn} = QF_{"vaen"mn} \left(\frac{PF_{emn}}{\theta_{emn} PF_{"vaen"mn}}\right)^{-ESVA_{mn}} \quad (9)$$

$$qf_{emn} = qf_{"vaen"mn} - af_{emn} + ESVA_{mn}\left(\dot{\theta}_{emn} + pf_{"vaen"mn} - pf_{emn}\right) \quad (10)$$

$$qf_{emn} = qf_{"vaen"mn} + ESVA_{mn}(pf_{"vaen"mn} + af_{emn} - pf_{emn}) \quad (11)$$

$$pf_{"vaen"mn} = \sum\nolimits_{e=VAEN} SHVAEN_{emn} \times [pf_{emn} - af_{emn}] \quad (12)$$

$$ps_{mn} = -ao_{mn} + \sum\nolimits_{e=OUT\_COMM} SHTC_{emn} \times [pf_{emn} - af_{emn}] \quad (13)$$

Using Equation 12, the weighted average price of energy and value-added (percentage changes) is determined, reflecting the weighted average price of primary production factors (excluding capital) along with the capital-energy composite. $SHVAEN_{emn}$ Shows the cost contribution of each input in this layer. Equation 13 illustrates the growth rate of the prices of produced goods, reflecting the weighted average cost of all inputs, encompassing intermediate inputs along with the composite of primary factors and energy. $SHTC_{emn}$ Denotes the cost share of the *e* input in the total production cost of good *m* in region *n*. According to Equation 13, the composite price will decrease if the input's productivity improves. Additionally, improvements in input productivity and an increase in Total Factor Productivity (TFP) hurt the supply price of goods. This research is designed to inform policymakers and stakeholders about the implications of renewable energy adoption, providing them with valuable insights into the economic and environmental impacts of energy transition scenarios in Iran.

4.4 Intermediate Goods Layer

$$QFD_{emn} = QFT_{emn} \left(\frac{PFD_{emn}}{\theta_{emn} PFT_{emn}}\right)^{-ESARM_{mn}} \quad (14)$$

$$qfd_{emn} = qft_{emn} + ESARM_{mn}(pft_{emn} - pf_{emn}) \quad (15)$$

$$QFM_{emn} = QFT_{emn}(\frac{PFM_{emn}}{\theta_{emn}PFT_{emn}})^{-ESARM_{mn}} \quad (16)$$
$$qfm_{emn} = qft_{emn} + ESARM_{mn}(pft_{emn} - pfm_{emn}) \quad (17)$$
$$pft_{emn} = SHRM_{emn} \times pfm_{emn} + (1 - SHRM_{emn}) \times pfd_{emn} \quad (18)$$

The demand for domestic intermedite inputs, $QFD_{emn,}$ and imported intermediate inputs, $QFM_{emn,}$ is derived in the intermediate layer. The rate of increase in the composite price of intermediate goods $(pft_{emn)}$ is equal to the weighted average of the percentage changes in the prices of domestic intermediate inputs $(pfd_{emn)})$ and foreign intermediate inputs (pfm_{emn}). $SHRM_{emn}$ Represents the cost share of the imported input *e* used in sector m*m* in region *n*. ESARM*ESARM* is the elasticity of substitution between domestic and imported goods, known as the Armington elasticity. Should the cost of local products go up, the need for foreign goods will increase. If the Armington elasticity increases, the intensity of the demand shift toward imported good will be greater.

4.5 Capital-Energy Layer

$$QF_{emn} = QF_{"ken"mn}(\frac{PF_{emn}}{\theta_{emn}PF_{"ken"mn}})^{-ESCE_{mn}} \quad e \in \{capital, energy\ composite(eny)\} \quad (19)$$
$$qf_{emn} = qf_{"ken"mn} - af_{emn} + ESCE_{mn}(pf_{"ken"mn} + af_{emn} - pf_{emn}) \quad (20)$$
$$pf_{"ken"mn} = \sum_{e \in KEN} SHKEN_{emn} \times (pf_{emn} - af_{emn}) \quad (21)$$

In the capital-energy composite layer, the ideal demand for both capital and the energy composite is represented as a function of relative prices and variations in technical inputs. $pf_{"ken"mn}$ and $qf_{"ken"mn}$ indicate the price and amount of the capital-energy combination, in which the composite price reflects the weighted average of the prices of capital and energy. If the productivity of energy $(af_{"eny"mn})$ increases, according to Equations 21 and 24, the price of the energy bundle will decrease. As a result, the energy demand will increase through the substitution effect. Conversely, according to Equations 19, 20, 22, and 23, it has a direct impact on the energy demand.

4.6 Energy Layer

$$QF_{emn} = QF_{"eny"mn}(\frac{PF_{emn}}{\theta_{emn}PF_{"eny"mn}})^{-ESEIT_{mn}} \quad e \in \{elctricity, non-electricity(nely)\} \quad (22)$$
$$qf_{emn} = qf_{"eny"mn} - af_{emn} + ESEIT_{mn}\left(pf_{"eny"mn} + af_{emn} - pf_{emn}\right) \quad (23)$$
$$pf_{"eny"mn} = \sum_{e \in ENY} SHENY_{emn} \times (pf_{emn} - af_{emn}) \quad (24)$$

The electricity demand and the composite of non-electricity are obtained from Equations 22 and 23, while the composite energy price is determined with Equation 24. $SHENY_{emn}$ Represents the cost share of electricity and non-electricity energy. If this elasticity alters, the demand ratio for clean energy could change, influencing carbon emission levels.

4.7 Non-Electricity Layer

$$QF_{emn} = QF_{"nely"mn}\left(\frac{PF_{emn}}{\theta_{emn}PF_{"nely"mn}}\right)^{-ESNL_{mn}} \quad e \in \{coal, non-coal(ncoal)\} \tag{25}$$

$$qf_{emn} = qf_{"nely"mn} - af_{emn} + ESNL_{mn}\left(pf_{"nely"mn} + af_{emn} - pf_{emn}\right) \tag{26}$$

$$pf_{"nely"mn} = \sum_{e\in NELY} SHNELY_{emn} \times (pf_{emn} - af_{emn}) \tag{27}$$

In the non-electricity sector, the ideal demand for the coal and non-coal composite is established, depending on the relative energy prices (Equations 25 and 26). Additionally, the price of non-electricity energy $(pf_{"nely"mn})$ is the weighted mean of the costs of coal and non-coal energy sources. It should be noted that $SHNELY_{emn}$ represents the cost share of each energy carrier in this layer.

4.8 Non-Coal Layer

$$QF_{emn} = QF_{"ncoal"mn}\left(\frac{PF_{emn}}{\theta_{emn}PF_{"ncoal"mn}}\right)^{-ESNC_{mn}} \quad e \in \{oil, gas, oil\ products\} \tag{28}$$

$$qf_{emn} = qf_{"ncoal"mn} - af_{emn} + ESNC_{mn}(pf_{"ncoal"mn} + af_{emn} - pf_{emn}) \tag{29}$$

$$pf_{"ncoal"mn} = \sum_{e\in NCOAL} SHNCOAL_{emn} \times (pf_{emn} - af_{emn}) \tag{30}$$

The three non-coal inputs are oil, natural gas, and petroleum products, with Equations 28 and 29 illustrating the optimal demand for these resources. The cost of the composite package of these inputs is defined by Equation 30. The greater the elasticity of substitution among these inputs ($ESNC_{mn}$), the more significant the impact of relative price changes on the demand for these inputs.

4.9 Base Load-Peak Load Layer

$$QF_{emn} = QF_{"egen"mn}\left(\frac{PF_{emn}}{\theta_{emn}PF_{"egen"mn}}\right)^{-ESBP_{mn}} \quad e \in \{peak\ load, base\ load\} \tag{31}$$

$$qf_{emn} = qf_{"egen"mn} - af_{emn} + ESBP_{mn}\left(pf_{"egen"mn} + af_{emn} - pf_{emn}\right) \tag{32}$$

$$pf_{"egen"mn} = \sum_{e\in EGEN} SHBP_{emn} \times (pf_{emn} - af_{emn}) \tag{33}$$

Base load and peak load are substituted for one another based on a CES function with the elasticity of substitution $ESBP_{mn}$ the result of cost minimization leads to the demand functions described by Equations 31 and 32. In contrast, the price index for base and peak load is given by Equation 33.

4.10 Peak Load Layer

$$QF_{emn} = QF_{"peak"mn}\left(\frac{PF_{emn}}{\theta_{emn}PF_{"peak"mn}}\right)^{-ESPK_{mn}} \quad e \in \{fossil\ fuel, renewables\} \tag{34}$$

$$qf_{emn} = qf_{"peak"mn} - af_{emn} + ESPK_{mn}\left(pf_{"peak"mn} + af_{emn} - pf_{emn}\right) \tag{35}$$

$$pf_{"peak"mn} = \sum_{e \in PEAK} SHPKL_{emn} \times (pf_{emn} - af_{emn}) \tag{36}$$

The replacement of peak load technologies takes place with the elasticity. $ESPK_{mn}$, which, in a sense, signifies the flexibility in replacing fossil fuels with renewable energy options. The cost of the peak load bundle is established by Equation 36, weighted by $SHPKL_{emn}$.

4.11 Base Load Layer

$$QF_{emn} = QF_{"base"mn}\left(\frac{PF_{emn}}{\theta_{emn}PF_{"base"mn}}\right)^{-ESBAS_{mn}} \quad e \in \{fossil\ fuel, renewables\} \tag{37}$$

$$qf_{emn} = qf_{"base"mn} - af_{emn} + ESBAS_{mn}(pf_{"base"mn} + af_{emn} - pf_{emn}) \tag{38}$$

$$pf_{"base"mn} = \sum_{e \in BASE} SHBSL_{emn} \times (pf_{emn} - af_{emn}) \tag{39}$$

Ultimately, in the final layer of the technology tree, the requirement for base load is obtained through a CES function that incorporates the elasticity of substitution $ESBAS_{mn}$ (Equations 37 and 38). $pf_{"base"mn}$ Denotes the weighted mean price of energy in the base load layer, with the weight applied ($SHBSL_{emn}$) represents the distribution of costs among various energy inputs in this layer. In the typical closure of the model, all technological coefficients, such as af and pf, are determined externally, while prices and quantities are determined internally. All substitution elasticities, parameters, and coefficients are adjusted according to the GTAP version 11 database.

4.12 Data and Scenario Design

The analysis utilizes the GTAP-Power version 11 database with the base year 2017, representing the latest available dataset (Aguiar et al., 2019). In this research, energy transition policies are simulated in the period 2020-2050. This database includes global input-output tables for 161 countries/regions worldwide. This study aggregates these 161 countries and regions into three regions: Iran, Iran's major trading partners in the electricity sector, and the rest of the world. Additionally, 76 sectors are aggregated into 13 key sectors for the analysis, ensuring a comprehensive and thorough examination of the data.

Table 2. Description of Sectors in the CGE Model

Sectors	Sector Description
Agriculture	Agriculture, hunting, fishing, and forestry
Coal	Coal
Oil	Oil

Sectors	Sector Description
Petroleum products	Petroleum, coal products
Gas	Gas, Gas manufacture, distribution
Energy-intensive products	Minerals nec, Chemical goods, Basic pharmaceutical goods, Rubber and plastic goods, Mineral goods nec, Ferrous alloys, Metals nec
Non-energy-intensive products	Bovine meat products,Meat products nec,Vegetable oils and fats,Dairy products, Processed rice, Sugar, Food products nec, Beverages and tobacco products,Textiles, Wearing apparel, Leather products,Wood products, Paper products, publishing, Metal products,Computer, electronic and optic,Electrical equipment,Machinery and equipment nec, Automobiles and components, Transportation devices not elsewhere classified, Products not elsewhere classified.
Electricity distribution and transmission network	Electricity: transmission and distribution
(RBL) Base load renewable electricity	Nuclear base load,Wind base load,Hydro base load,Oil base load, Other base load
(FBL) Base load fossil electricity.	Coal base load, gas base load
(FPL) Peak load fossil electricity.	Gas peak load, oil peak load
(RPL) Peak load renewable electricity.	Hydro peak load, solar peak load
Services	Water, Commerce, Lodging, Catering and service, Storage and support operations, Communication, Business services not elsewhere classified, Leisure and additional services, Public Administration and defense, Education, Human health and social services, Building, Real estate operations, Transport not elsewhere classified, Water transport, Air travel, Financial services not elsewhere classified, Insurance

***Source**: Calculated by the author*

One of the critical issues in Iran's economy today is the electricity imbalance, which leads to periodic blackouts. Therefore, electricity imports can help address these imbalances. For this reason, in this study, countries with Iran trade electricity are considered separate regions. Regions illustrate the volume of Iran's electricity trade with its trading partners. The chart below shows the share of each neighboring country in electricity exchanges with Iran in the year 2021. Iran's major export markets are Iraq, Afghanistan, and Pakistan. Iran has bilateral electricity exchanges with Armenia and Azerbaijan, while it imports electricity from Turkmenistan. Additionally, in recent years, due to some financial disputes, there has been no electricity exchange between Turkey and Iran.

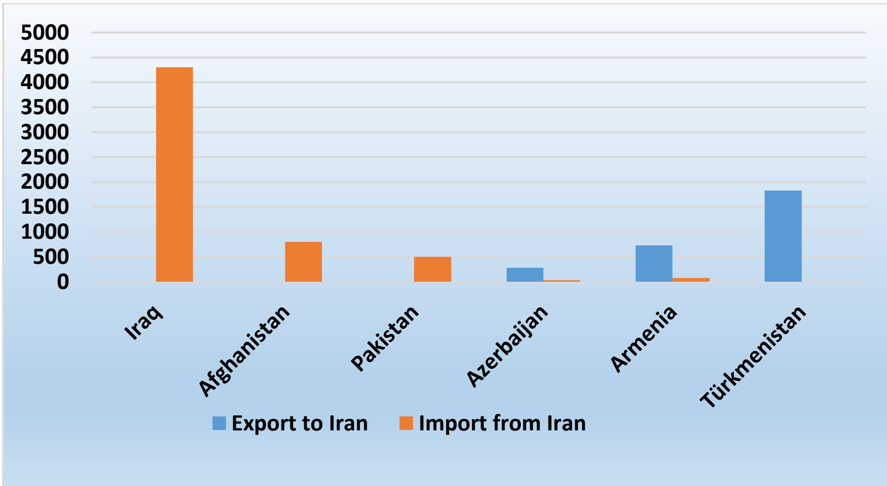

Figure 3. Iran's Electricity Exports and Imports with Neighboring Countries

Source: *Detailed Statistics of Iran's Electricity Industry for Strategic Management in 2021, Tavanir Specialized Holding Company.*

Table 3 shows the emission levels and the percentage of emissions for the selected countries/regions in this study, highlighting the importance of Iran's major trading partners in the energy sector regarding energy consumption and their share of global emissions. The data in Table 3 indicates that Iran's six trading partner countries in the energy sector account for 1.32% of global carbon emissions. Among the countries listed in Table 3, Iran exports electricity to Iraq, Afghanistan, and Pakistan, has bilateral electricity exchanges with Armenia and Azerbaijan, and imports electricity from Turkmenistan.

Table 3. Share of CO2 Emissions and Energy Consumption of Selected Countries

Region	Energy consumption (TWH)	Share of global CO2 emissions (percentage)	Region	Energy consumption (TWH)	Share of global CO2 emissions (percentage)
Iran	3531	1.86	Afghanistan	27	0.03
Türkmenistan	445	0.17	Pakistan	937	0.54
Iraq	698	0.48	Azerbaijan	228	0.01

Source: *U.S. Energy Information Administration (2023); Energy Institute- Statistical Review of World Energy (2024); Global Carbon Budget (2023)*

Current trends in the energy market indicate a significant shift among countries toward using renewable energy, particularly in electricity generation, alongside significant advancements in the electrification of transportation systems. Given the importance of renewable energy in electricity production and the requirements of the Seventh Development Plan, which mandates that 10% of the country's electricity be generated from renewable sources, this study designs scenarios based on global literature on energy transition (as discussed in the theoretical framework). It considers domestic advantages and the policies of the

Seventh Development Plan. The scenarios examined in this study are outlined in Table 4.

It is important to note that in implementing the scenarios, a zero Armington elasticity is applied to all variables except exports and imports. However, a regional Armington elasticity of one is applied to analyze the effects of exports and imports between Iran and other regions. This allows for observing the effects of relative price changes and their sensitivities in the context of trade.

Table 4. Scenario Design for This Study

Scenario	Definition
S1	A 2% increase in the share of electricity generated from renewable energy every two years until 2030 (fulfilling the Seventh Development Plan) and projecting it until 2050.
S2	A 5% increase in the share of electricity generated from renewable energy while keeping the share generated from fossil fuels constant every two years until 2050.
S3	A 5% increase in the share of electricity generated from renewable energy, alongside a 5% decrease in the share generated from fossil fuels, every two years until 2050.

Source: *Calculated by the author*

5. Empirical Results of the Model

In this study, energy transition policies were simulated under three scenarios for 2020-2050. Below, the results for each scenario are presented in terms of selected key economic variables, including real GDP, inflation rate (ppriv), household welfare (up), total electricity imports of Iran from all regions (qi), total electricity exports of Iran to all regions (qxw), (qiwreg) Total imports and (qxwreg) Total exports. Additionally, the environmental impacts of the energy transition in Iran are analyzed using variables such as total carbon emissions (gco2t), carbon emissions from firms in the production sector (gco2fsff) and (gco2int) carbon emission intensity.

5.1 Scenario S1

Scenario S1 examines the policies of the Seventh Development Plan regarding renewable energy. In this scenario, in line with the Seventh Development Plan, electricity generation from renewable energy will reach 10% by 2030. The results in Table 5 show that under this scenario, real GDP exhibits an upward trend from the beginning until 2050, increasing by 0.07% in 2030 and 0.22% in the final year. This increase can be attributed to the rise in renewable energy supply, which reduces the price of these energy sources in the production mix, lowering production costs and boosting GDP.

The inflation rate under Scenario S1 is declining, decreasing by 0.07% in 2050. The disinflationary effects of this scenario may be due to the increased energy supply, although the modest impact reflects the small share of renewable energy in the energy mix. Household welfare also shows a slight upward trend, similar to the previous variables, as increased production leads to higher income levels. By the end of the simulation period, household welfare increased by 0.05%.

Iran's electricity imports from its energy trading partners show minimal changes under Scenario S1, with a 0.7% increase by 2030 and a 0.5% increase by 2050. On the other hand, Iran's electricity exports exhibit an upward trend, increasing by 36.58% by the end of 2050. Changes in total exports and imports have been such that total imports initially had a positive trend, but in recent years have been decreasing, decreasing by 0.01 percent in the final year. Total exports have had a positive trend in all years and increased by 0.56 percent in 2050.

Table 5. Economic Effects of Implementing Scenario S1

Variable/year	2022	2026	2030	2034	2038	2042	2046	2050
GDP	0.04	0.04	0.07	0.01	0.14	0.17	0.19	0.22
ppriv	0.00	0.00	0.00	-0.01	-0.02	-0.04	-0.05	-0.07
up	0.01	0.02	0.03	0.03	0.04	0.05	0.05	0.05
qiw	0.39	0.60	0.70	0.75	0.74	0.70	0.62	0.50
qxw	3.63	7.59	11.83	16.29	20.99	25.94	31.12	36.58
qiwreg	0.01	0.02	0.04	0.04	0.02	-0.01	0-0.5	-0.10
qxwreg	0.03	0.07	0.12	0.19	0.28	0.37	0.47	0.56

Source: *Calculated by the author*

With the implementation of Scenario S1, the trends in environmental variables have been declining. As shown in Chart 4, total carbon emissions exhibit a downward trend until 2050, decreasing by 1.33% in that year. Similarly, carbon emissions from firms in the production sector also show a decline, decreasing by 1.93% in 2050, Carbon emission intensity has also decreased by 1.55% by applying this scenario. Since the electricity sector accounts for the largest share of carbon emissions, the increase in the share of renewable electricity directly impacts reducing carbon emissions, as illustrated in the chart below.

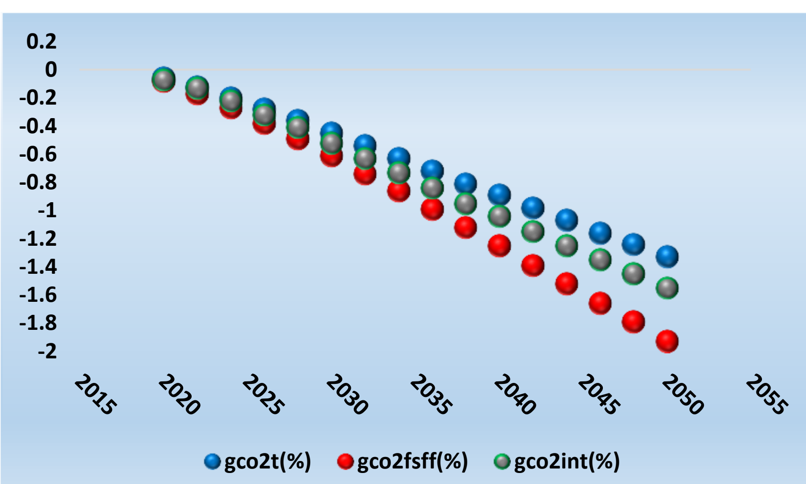

Figure 4. Environmental Effects of Implementing Scenario S1
***Source:** Calculated by the author*

5.2 Scenario S2

In this situation, the proportion of renewable energy in electricity production rises by 5% every two years, while the proportion of fossil fuels remains unchanged. The results are presented in Table 6. Similar to the previous scenario, real GDP shows an upward trend throughout the years, increasing by 0.7% in 2050. This represents approximately a threefold increase in GDP compared to the previous scenario, driven by a 3% increase in renewable electricity generation. This increase in renewable energy supply reduces production costs, ultimately boosting GDP. The inflation rate remains relatively stable initially but shows a declining trend from 2029 onward, decreasing by 0.1% by the end of the study period. This decline is attributed to the increased energy supply. Household welfare also exhibits an upward trend, increasing by 0.07% in 2030 and 0.36% in 2050. Similar to the previous scenario, this improvement in welfare is likely due to higher income from increased production. Iran's electricity exports show significant changes under this scenario, increasing by 126.2% by the end of the period. On the other hand, electricity imports initially increased until 2038 but then declined by 3.55% in 2050, Total exports and imports have also shown an increasing trend, but the changes in total imports have been very small, while total exports have increased by 1.45% in 2050.The results of this scenario serve as a sensitivity analysis, demonstrating that increasing the share of renewable electricity generation aligns with the outcomes of the previous scenario but with a more pronounced impact.

Table 6. Economic Effects of Implementing Scenario S2

Variable/year	2022	2026	2030	2034	2038	2042	2046	2050
GDP	0.03	0.1	0.18	0.28	0.38	0.48	0.59	0.7
ppriv	0.00	0.00	-0.01	-0.03	-0.05	-0.08	-0.1	-0.1
up	0.01	0.04	0.07	0.1	0.13	0.16	0.22	0.36
qiw	0.94	1.34	1.28	0.97	0.32	-0.63	-1.90	-3.55
qxw	9.23	19.97	32.32	46.33	62.36	80.71	101.7	126.2
qiwreg	0.02	0.07	0.11	0.12	0.10	0.05	0.01	0.06
qxwreg	0.10	0.21	0.35	0.55	0.79	4.06	1.33	1.45

***Source:** Calculated by the author*

The chart illustrates the impact of implementing Scenario S2 on environmental variables. The results indicate that this scenario leads to a more significant reduction in carbon emissions compared to the previous scenario. Specifically:Total Carbon Emissions (gco2t): Decrease by 4.27%.Carbon Emissions from Firms in the Production Sector (gco2fsff): Decrease by 6.28%.These reductions are approximately three times greater than those observed in the previous scenario. Carbon emission intensity has also decreased by 4.97%.

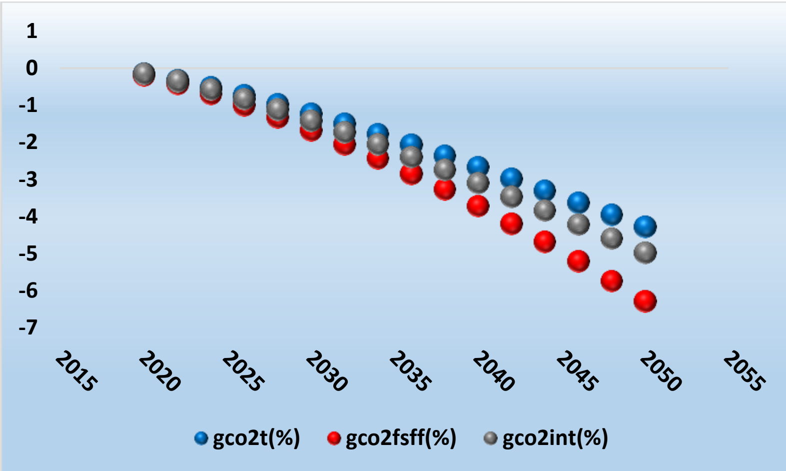

Figure 5. Environmental Effects of Implementing Scenario S2
Source: *Calculated by the author*

5.3 Scenario S3

In this scenario, the share of electricity generated from renewable energy increases by 5% every two years until 2050, while the share of electricity generated from fossil fuels decreases by 5% every two years until 2050. The results of implementing Scenario S3, as shown in Table 7, indicate that real GDP declines throughout the years, unlike the previous two scenarios. Specifically, GDP decreases by 1.32% in 2030 and 2.37% in 2050. This decrease can be linked to the reality that a large share of Iran's electricity comes from fossil fuels. The 5% reduction in fossil fuel-based energy supply leads to a decrease in overall energy supply, which increases energy prices on one hand and reduces demand for fossil fuels on the other. This, in turn, lowers production, resulting in a decline in GDP. The inflation rate will decline until 2032 but rise by 1.43% in 2050. This rise in inflation is due to the reduced energy supply and higher energy prices resulting from the implementation of Scenario S3. Household welfare declines throughout the years due to reduced production, higher energy prices, and increased production costs. Welfare decreases by 2.49% in 2030 and 3.17% in 2050. Electricity imports increased throughout the years, reaching a 25% increase by 2050. On the other hand, electricity exports initially declined but began to rise after 2025, increasing by 75.12% in 2050. Total imports have decreased in all years and decreased by 1.99% in 2050, while total exports have had an upward trend and increased by 1.90% in the final year.

Table 7. Economic Effects of Implementing Scenario S3

Variable/year	2022	2026	2030	2034	2038	2042	2046	2050

GDP	-0.28	-0.78	-1.32	-1.8	-2.17	-2.39	-2.45	-2.37
ppriv	-0.38	-0.49	-0.3	0.04	0.44	0.84	1.17	1.43
up	-1.03	-1.89	-2.49	-2.9	-3.14	-3.26	-3.28	-3.17
qiw	12.19	19.93	24.66	27.85	29.34	29.29	27.91	24.99
qxw	-1.63	1.54	7.74	15.87	26.30	39.31	55.25	75.12
qiwreg	-2.12	-3.86	-4.72	-4.88	-4.51	-3.80	-2.93	-1.99
qxwreg	3.65	5.43	5.63	5.19	4.38	3.47	2.64	1.90

Source: *Calculated by the author*

The chart illustrates that the environmental impacts of implementing Scenario S3 are significantly more significant than those of the previous two scenarios. Under this scenario, total carbon emissions are declining, decreasing by 10.89% in 2050. Additionally, carbon emissions from firms in the production sector decrease by 16.04% in 2050representing a two-and-a-half-fold reduction compared to the previous scenario. , Carbon emission intensity also decreased by 8.52% in the final year. These reductions in carbon emissions can be attributed to two main factors: Increase in Renewable Energy Share: The higher share of renewable energy in electricity generation directly reduces carbon emissions. Decrease in Fossil Fuel Share: The reduction in the share of fossil fuels in electricity production further contributes to the decline in emissions.

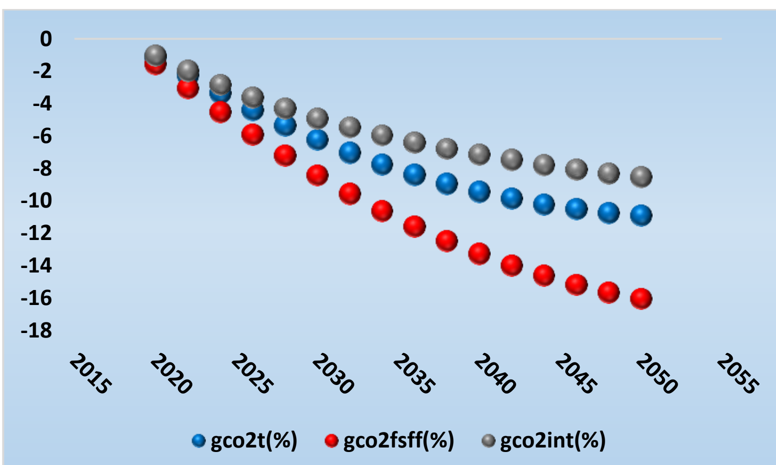

Figure 6. Environmental Effects of Implementing Scenario S3
Source: *Calculated by the author*

6. Conclusion & Policy Recommendations

This study employs a dynamic computable general equilibrium (CGE) model to examine the economic and environmental impacts of energy transition in Iran. Three scenarios for energy transition were analyzed. The results indicate that the first scenario yields a "double dividend," where welfare and GDP increase while carbon emissions decrease. This suggests that the Seventh Development Plan's policies on renewable energy production have positive economic and environmental effects. However, the magnitude of these effects is modest, likely due to the small share of renewable energy in Iran's energy mix.The second scenario aligns with the first regarding the direction of impacts but shows more significant changes. On average, the economic impacts of the second scenario are three times greater than those of the first. In comparison, the environmental impacts are 3.5 times more significant, resulting in a more substantial reduction in carbon emissions. Therefore, both the first and second scenarios—where the share of renewable energy increases while the share of fossil fuels remains constant—demonstrate that increasing renewable energy production beyond the targets set in the Seventh Development Plan amplifies the positive economic and environmental effects.In contrast, the third scenario shows different economic outcomes than the previous two. Both GDP and welfare decline while inflation rises. These negative changes are attributed to reduced fossil fuel production, constituting a significant portion of Iran's energy production. If fossil fuel production is reduced in line with international climate conferences, it could adversely affect Iran's economy, necessitating serious attention from policymakers. However, the third scenario significantly reduces carbon emissions compared to the previous scenarios, aligning with the goals of international climate agreements.

Based on the results of the dynamic CGE model, the following policy recommendations are proposed:

1. In two of the scenarios, total imports have decreased. This decrease in imports due to sanctions is greater than the decrease in exports, which means an improvement in the trade balance under sanctions. Therefore, policies to support export-oriented production during periods of increased sanctions are highly recommended.
2. Implementation of the Seventh Development Plan: The positive economic and environmental effects highlight the need for policymakers to prioritize its implementation within the specified timeframe.
3. Promotion of Renewable Electricity Production: Increasing renewable electricity production while maintaining fossil fuel-based electricity production is a win-win strategy, boosting welfare and reducing carbon emissions. Policymakers should focus on renewable energy to achieve economic and environmental goals simultaneously.
4. Balanced Approach to Fossil Fuel Reduction: If the primary goal is to achieve environmental targets, policymakers should significantly increase the share of renewable energy rather than reduce fossil fuel production, as the latter could harm welfare and GDP.
5. Compensatory Measures for Welfare Loss: If reducing fossil fuel production is deemed necessary, policymakers should implement compensatory measures, such as subsidies or incentives for households, to mitigate the negative impacts on welfare and GDP.

Comparing the results with international studies shows that the results are consistent with the present study. (Moyo, 2024) in a study examining the increase in the share of renewable energy for South Africa, found that the growth rate of GDP increased by 0.25%, which is 0.3% higher than the growth in Iran. Household well-being has also increased to a greater extent than in Iran. Carbon emissions have also been reduced to a greater extent. The energy transition results for Saudi Arabia show that both the direction and the rate of change in economic and environmental variables are similar to those of Iran (Al-Qahtani, 2025). The energy transition in Germany was examined by Muller (2023) and found that high investment in the renewable energy sector has led to an increase in both economic growth and household welfare by 0.30 and 0.10 percent, respectively, which is higher than in Iran, and a reduction in carbon emissions of 2 percent, which is still higher than the reduction in emissions in Iran. Li (2022) examined the energy transition for China, and Singh (2020) examined the energy transition for India, both of which obtained results similar to previous studies and in support of the results of the present study.

Author Contributions

In all stages of writing the article, including Conceptualization, methodology, validation, formal analysis, preparation of original draft, review and editing, All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest

The authors declare no conflict of interest.

Data Availability Statement

Data can be made available upon request.

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