



Simulating the Effects of Emission Trading on The Structural Change in The Iran's Economy

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Highlights

- The effects of carbon emissions trading on structural changes in Iran's economy.
- Application of a multi-regional dynamic computable general equilibrium model.
- A decline in the share of energy-intensive industries and fossil-fuel-based electricity.
- The share of the services sector decreased by 2.65% in 2050 compared to 2015.
- An increase in the share of renewable electricity

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Abstract

Carbon emissions trading is one of the most important policy instruments for reducing greenhouse gas emissions, serving as an effective response to climate change, which has garnered global attention. Given the rising trend of carbon emissions in Iran and the country's ranking as the sixth largest emitter of carbon dioxide globally, examining the impacts of implementing such a policy at both national and regional levels is highly important. In this study, utilizing a dynamic computable general equilibrium (DCGE) model, the regional carbon market between Iran and selected trading partners (China, India, Turkey, and the United Arab Emirates) was simulated for the 2050 horizon, and its impacts on Iran's environmental performance, income, structural changes, and gross domestic product (GDP) were evaluated. Results showed that implementing the carbon market would lead to a 40.29% reduction in carbon dioxide emissions in Iran and a 3.33% decline in GDP. The output share of the fossil-fuel-based power sector, energy-intensive industries, and services decreased by 15.79%, 7.13%, and 2.65%, respectively, whereas electricity from renewable energy increased by 22.1%. Furthermore, due to lower emissions than the assigned cap, Iran could earn an income of \$ 10,162.89 million by selling surplus emission permits. This income could be used to develop renewable electricity generation and support industries in financing innovation enhancement and productivity improvement. Therefore, based on the results, developing the carbon emissions market is recommended to optimize Iran's energy structure and that of its major trading partners.

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1. Introduction

Greenhouse gas emission is the foremost cause of climate change, especially global warming, in addition to the emission of pollution and environmental destruction. Surveys indicate that the rate of rise in the earth's temperature has almost doubled compared to the last fifty years, and by the year 2100, the earth's temperature is predicted to increase by 6.4 degrees Celsius (Barros et al., 2014). According to the International Energy Agency (IEA, 2024), global CO₂ emissions reached approximately 37.4 billion tons in 2023, representing a 5.3 percent increase from 2015. About 83 percent of these emissions originate from the consumption of fossil fuels. Moreover, according to the Global Carbon Project (2023), China, the United States, India, Russia, and Japan together account for more than 60 percent of total global CO₂ emissions (Friedlingstein et al., 2023).

The need to strengthen efforts to reduce greenhouse gas emissions to tackle climate change has become a primary global concern in recent decades (Duarte et al., 2018). Currently, a significant goal of energy and environmental policies is reducing greenhouse gas emissions and atmospheric pollutants. In achieving the development of carbon trading markets, international commitments — foremost among them the Kyoto Protocol and its related obligations — are undeniable among various countries. The three innovative mechanisms of the Kyoto Protocol are the Clean Development Mechanism¹, Joint Implementation², and Emissions Trading (Kuriyama & Abe, 2018).

Carbon emissions trading is a form of trade and market using a price mechanism to control resource allocation and specifically concentrates on carbon dioxide reduction targets, and today is the majority of global emissions trading. Carbon emissions trading is a widely used method by countries aiming to meet or exceed their commitments to reduce carbon emissions to mitigate climate change. In carbon trading, countries with higher carbon emissions have the option to purchase more emission rights. Conversely, countries with lower emissions can relinquish their surplus quotas, thus enabling carbon emission rights trading (US Commodity Futures Trading Commission 2011). A carbon emissions trading policy is a market-based environmental regulation policy that can enhance the incentives of enterprises to lower carbon emissions (Dai et al., 2022). Nordhaus (2007) indicated that emissions trading systems can improve economic efficiency. Also, Permit trading can grow production and profit margins (Foramitti et al.,

¹The implementation process of the Clean Development Mechanism involves developed countries financing greenhouse gas (GHG) emission reduction projects in developing nations, thereby fulfilling part of their own emission reduction commitments. This mechanism not only assists developing countries in implementing emission mitigation policies but also enables them to attract foreign investment, facilitating the initiation of environmentally sustainable economic projects.

² Joint Implementation (JI) was introduced under Article 6 of the Kyoto Protocol as a mechanism for cooperative projects. This mechanism enables Annex I countries to collaborate on projects with other developed countries in Annex I that result in reduced greenhouse gas (GHG) emissions, as the cost of implementing such projects may be lower in certain countries. The application of this approach is subject to specific conditions and requirements stipulated in Article 6 of the Protocol.

2021). Therefore, emissions trading schemes can significantly impact green technology (Du et al., 2021). According to the ICAP (2024) report, there are currently 36 emissions trading systems active worldwide, covering approximately 18 percent of total global greenhouse gas emissions. Additionally, 22 other systems are currently under development or consideration, primarily located in South America and Southeast Asia. The global carbon market reached a trading volume of approximately USD 949 billion in 2023. In the same year, the average price per ton of carbon dioxide in the European Union and Chinese markets was EUR 83 and USD 11.19, respectively (London Stock Exchange Group [LSEG], 2023). Furthermore, according to the World Bank (2024), 75 carbon pricing instruments are currently active worldwide, collectively covering approximately 24 percent of global greenhouse gas emissions. Revenues from these markets reached a record USD 104 billion in 2023, with the majority of the funds allocated to support climate and environmental programs (World Bank, 2024).

Researchers have examined the effects of carbon trading policies on emission reductions from multiple perspectives. Several studies have found that such policies can substantially reduce carbon dioxide emissions (Zhou et al., 2019a,b,c; Zhang et al., 2020a,b; Lin & Jia, 2019; Lv & Bai, 2021; Feng et al., 2024). However, other studies have suggested that the impact of carbon trading policies on emission reductions is limited and varies across regions with different characteristics (Zhang et al., 2019a,b,c). The influence of carbon trading schemes on energy-intensive sectors is generally stronger than on other sectors, although the magnitude of the effects varies. This approach is particularly effective in improving green manufacturing performance for energy-intensive firms (Sun et al., 2022). Indeed, with the implementation of carbon emissions trading, the costs associated with carbon emissions from conventional energy sources also rise. Consequently, fossil fuel prices increase, encouraging users to shift toward clean, renewable energy sources (Huang et al., 2023). Generally, in developed countries and certain emerging economies, carbon emissions trading schemes have successfully curtailed enterprises' reliance on fossil fuels. As a result, these policies contribute to reductions in carbon emissions, improvements in energy efficiency, and enhancements in the energy consumption structure (Böhringer et al., 2006; Martin et al., 2014; Diaz-Rainey & Tulloch, 2018; Dewaelheyns et al., 2023; Zhang et al., 2024). Several studies investigating the effects of pilot carbon emissions trading policies on different aspects of energy use—including total energy consumption (Jiang et al., 2022), energy intensity (Geng & Fan, 2021), energy efficiency (Hong et al., 2022), energy investment (Xie & Zheng, 2020), and renewable energy development (Zhang et al., 2022), aimed at establishing a carbon market—have found that such experimental policies can substantially reduce both the total energy consumption and its intensity within a region. Moreover, these policies enhance energy efficiency and encourage investment in low-emission power generation technologies within pilot regions. Additionally, these policies typically contribute to the broader development of renewable energy sources (Jia et al. 2024). Thus, another aim of the formation of a carbon

market is to encourage change in the economic structure. Growth with economic restructuring results in development and progress for any country. Changing structure in economic discussions is the alternation in the relative share of sectors in the economy, in terms of production and their used factors, and structural change is the change in the relative weight of macroeconomic indicators, such as employment, production, national expenditures, exports and imports, etc (Eatwell et al. 1987).

The definition of structural change has been widely adopted in various studies and research in this field. Major changes in employment, output, and consumption structure during the process of economic development are an empirically proven fact. This phenomenon is summarized under the term structural change (Kuznets, 1957; Boppart, 2014; Kongsamut et al., 2001). According to the International Energy Agency (IEA, 2024), Iran's energy intensity is approximately twice the global average, and the country's primary energy mix is dominated by fossil fuels, with a share exceeding 90 percent. Seventy percent of Iran's total CO₂ emissions from the industrial sector are attributed to energy-intensive industries, including oil, gas, petrochemicals, steel, and cement. Based on statistics published in 2022, Iran ranks sixth with 1.9% of the total carbon dioxide emissions globally (Statistical Review of World Energy 2023). In compliance with evidence from Iran's energy balance sheet in 2020, the total carbon dioxide emissions in Iran are 667,967,917 tons, of which the power sector has 29.95%, the domestic, commercial, and public sector has 24.39%, the transportation sector has 21.19%, and the industrial sector has 19.14%. Correcting this trend requires the implementation of environmental and energy policies that are consistent with international commitments. Implementing a carbon emissions trading policy through a market-based mechanism implicitly sets a price for carbon emissions, requiring firms to purchase or hold allowances for each unit of carbon dioxide emitted. This leads to increased production costs in energy-intensive sectors, consequently resulting in changes in the composition of production inputs. Under these conditions, firms tend to substitute low-carbon inputs, such as renewable energy and more efficient technologies, for high-carbon inputs, such as fossil fuels. The consequence of this process is a shift in the share of output from various sectors in the country's gross domestic product, ultimately leading to a structural change in the economy (Liu et al., 2022; Zhang & Bi, 2023; Tang et al., 2025). Recent studies indicate that emissions trading systems can redirect production from heavy, energy-intensive industries toward service- and technology-oriented sectors, which, while reducing energy intensity, steer the economic structure toward higher efficiency and lower-carbon production (Jia et al., 2024; Li et al., 2024). Accordingly, the implementation of this policy in Iran is expected to lead to a restructuring of the country's economic system, accompanied by changes in production composition and sectoral shares of gross domestic product.

The aim of the present study is to evaluate the implementation mechanism of the carbon emissions market as a policy instrument for reducing carbon

emissions with minimal adverse effects on production. For this purpose, a carbon emissions trading market between Iran and some of its major trading partners (China, India, Turkey, and the United Arab Emirates) is simulated using the GTAP-E-Power-S model to assess the policy's impact on carbon dioxide emissions, revenue, and structural changes in Iran's economy. Therefore, the research questions are as follows: What are the effects of the carbon market on carbon dioxide emissions, gross domestic product, government or implementing authority revenue from the carbon market, and changes in sectoral output shares (economic structure) in GDP?

The remainder of the paper is structured as follows: Section 2 presents the theoretical framework; Section 3 reviews the literature on ETS studies across different countries; Section 4 describes the modeling approach, database, and scenario design; Section 5 reports the empirical results and examines the impacts of the carbon market on environmental performance, income, structural change, and GDP in Iran; Section 6 conducts a systematic sensitivity analysis; Section 7 provides the discussion; and finally, Section 8 offers the conclusions and policy recommendations.

2. Theoretical Framework

Following the formal ratification of the Kyoto Protocol in 1997, the concept of carbon emission trading became a core component of emissions trading programs. The Kyoto Protocol introduced three market-oriented approaches: Clean Development Mechanism (CDM), Joint Implementation (JI), and Emissions Trading (ET). (Mozayani et al., 2020). The United States pioneered the world's first legally binding greenhouse gas emissions trading system in 2003. Shortly after, in 2005, the European Union—comprising 28 member states—launched the EU Emissions Trading System (EU-ETS), which has grown to become the world's leading carbon market. (Hou et al., 2024). Since then, developed countries have introduced or implemented various greenhouse gas emissions trading schemes (Sanin et al., 2015), which have significantly promoted emission reductions. Examples include the UK Emissions Trading Group, the European Union's cap-and-trade framework, the Chicago-based Climate Exchange, and the Australian National Registry (Li & Jia, 2016). Carbon emissions trading policies originate from environmental regulations. Academic inquiry into the influence of such regulations dates back to Pigou's welfare economics theory, which introduced the concept of environmental externalities and recommended government intervention as a remedy (Pigou, 1912). Pigou proposed that governments should manage market externalities by implementing economic tools such as subsidies and taxes—measures that have come to be known as the Pigouvian tax. Conversely, Coase (1960) formulated his 'non-intervention' theory, positioning markets as the most effective means for regulating emission rights and addressing environmental externalities. This theoretical perspective later formed a foundation for what is now known as environmental property rights. Building on this, Dales (1969) proposed the emissions rights exchange mechanism for attaining Pareto efficiency in the

allocation of environmental resources. Dales argued that the assignment of tradable pollutant emission quotas would enhance how environmental resources are allocated. Thus, market-based greenhouse gas emissions trading emerges as a strategy to improve the efficiency of allocating environmental resources.

Montgomery (1972) theoretically explained that implementing a greenhouse gas emissions trading system can reduce the social costs of pollution. Furthermore, a flexible, market-based greenhouse gas reduction system outperforms approaches in which emission reductions are compulsory (Hou et al., 2024). Currently, carbon emissions trading is recognized as an effective instrument for reducing emissions at the international level (Dong et al., 2019). The Emissions Trading System is considered the primary cost-efficient mechanism for controlling carbon emissions (Cecchini et al., 2018; Jiang et al., 2018; Lee & Zhang, 2012; Tang et al., 2016; Wang et al., 2016a; Wang et al., 2016b). Emissions trading systems are categorized into two types: 1) cap-and-trade, and 2) baseline-and-credit (Buckley et al., 2005). The U.S. Environmental Protection Agency has identified cap-and-trade systems as a cost-effective solution (Boswell & Lee, 2002). In the cap-and-trade approach, emission limits are established, and trading incentivizes firms to innovate toward lower emissions. Each firm receives an initial carbon emission permit as its cap and may trade permits based on actual performance (Benjaafar et al., 2012; Li et al., 2018). Researchers have shown that carbon emissions trading policies can promote energy saving and emissions reduction by driving transformation in the energy structure. (Hou et al., 2024). ETSs may also play a significant role in promoting renewable energy development. First, when fossil fuel energy firms enter an ETS, electricity production costs increase due to higher carbon emission expenses. To reduce emissions, firms decrease fossil fuel energy generation, shifting the energy production structure toward renewables (Chen et al., 2020; Liu & Zhang, 2021). Second, ETSs can generate additional revenue for renewable energy projects (Lin & Jia, 2020). Emissions trading systems (ETS) create an economic incentive for reducing CO₂ emissions, encouraging firms to reassess the composition of their production activities. Sectors with higher emission intensity face increased production costs, resulting in a reduced share in gross domestic product, while low-carbon and technology-oriented sectors gain a larger share of output (Li & Zhao, 2024; Chai et al., 2022; Colmer et al., 2025). Empirical studies indicate that ETS not only reduces greenhouse gas emissions but also steers the economic production structure toward higher efficiency and lower carbon intensity. In other words, the share of energy-intensive industries decreases while the share of low-carbon and technology-oriented sectors increases, thereby improving resource allocation and overall economic efficiency (Zhao et al., 2022; Gao et al., 2025). In this study, structural change refers to changes in the share of output of different sectors relative to total gross domestic product. Additionally, for the structural change index, the difference between the growth rate of each sector's output and the growth rate of gross domestic product was used. A negative value indicates a decline in the sector's

share, while a positive value indicates an increase in the sector's share of total output.

3. literature review

Carbon emissions trading policy, as one of the most effective economic instruments for reducing greenhouse gas emissions, has attracted widespread attention. Most studies in this field have analyzed the environmental, economic, and structural impacts of ETS using various approaches and models. Based on this, they can be organized into several main themes, with the studies structured around the following axes:

3.1. Studies on the impact of ETS on CO₂ emissions

Meng et al. (2018) measured the effects of an ETS established to fulfill Australia's global commitments using a computable general equilibrium model to shrink emissions by 2020. The simulation results indicate that to reduce emissions by 12%, the ETS allowance price is estimated to be \$25 per ton of carbon. These results also demonstrate that the ETS can effectively reduce greenhouse gas emissions with minimal economic impact, while significantly increasing the generation of renewable electricity.

Hou et al. (2024) examined the effect of the carbon trading policy on the efficiency of carbon emissions in their study, utilizing China's yearly panel dataset spanning the period from 2004 to 2019. The model used in this study is DID. The findings indicated that a carbon trading policy not only immediately enhances the efficiency of carbon emissions but also indirectly enhances it through industrial structure upgrades and modifications in energy consumption patterns. The study demonstrated that the carbon trading policy effectively promotes the reduction of carbon emissions at the regional level, while also reducing air pollutants, including sulfur dioxide.

Xu et al. (2025) applied the DID model for assessing the effects of the national carbon emissions trading scheme regarding China's thermal power plants. The findings revealed that the adoption of the ETS significantly reduced CO₂ emissions. However, the magnitude of this effect differed across provinces, with institutional characteristics and local economic conditions playing a significant role in shaping the extent of emission reductions. Overall, China's ETS serves as an effective policy instrument for mitigating greenhouse gas emissions in the power generation sector.

3.2. Studies on the economic and structural impacts of ETS

Lin & Jia (2019) studied the effects of the national emissions trading scheme on China's economy, energy sector, and environment through a CGE model. The study concluded that China's national ETS is expected to exert a detrimental effect on GDP, ranging between 0.19% and 1.44%, equivalent to 0.16–1.23 trillion yuan, and may also lead to a surge in electricity prices. Nevertheless, the

rise for prices of other goods is projected to remain smaller than the increase in electricity prices. The study argues that even if solely the electricity sector participates in the ETS, the impact of China's emission reduction is projected to be substantial.

Huang et al. (2019) assessed a national ETS within China through a computable general equilibrium (CGE) model. The research findings indicated that first, unemployed in the country's energy-consuming industries (such as construction and coal) is expected to rise. By 2050, employment in the coal industry can be expected to decline by more than 75%. Second, the establishment of an ETS can positively affect overall economic development. Indeed, implementing a national ETS can elevate GDP by 3% by 2050. Third, if the carbon market in China expands to all industries, its revenue will continuously rise, reaching a maximum of 2,278 billion yuan (\$336 billion), making it the world's leading carbon market.

Nong et al. (2020) examined the economic and environmental effects of the ETS within Vietnam using the CGE model. The results indicate that limiting participation to certain industrial sectors in the ETS system impacts the national economy by reducing real GDP by 4.57%. However, when all industries join the ETS market, the country is exposed to notably fewer adverse effects (i.e., real GDP decreases by 1.78%). In both ETS designs, the coal extraction, manufacturing, transportation, and electricity sectors are strongly affected. Nevertheless, the crude oil and natural gas industries will expand production as a result of coal substitution. Overall, emission levels from fossil fuel combustion, under this policy, will crucially decrease, especially in the electricity generation sector.

Han et al. (2023) investigated emission reduction prospects within China's energy sector by applying the GTAP-E-Power-S model to bilateral international greenhouse gas emissions trading systems. Their findings indicated that, under a domestic ETS scenario, China's real GDP would decline by about 0.79%. However, establishing ETS links between China and India or Russia could lower the carbon price from \$7.80 per ton to \$2.16 and \$6.79 per ton, respectively, enabling emission increases of 1.14% and 7.05% in the energy and energy-intensive industries without breaching NDC commitments. Conversely, integrating China's ETS with those of the United States or the European Union would raise the carbon price to \$13.29 and \$9.76 per ton, respectively, resulting in emission reductions of 5.45% and 2.24% in the energy and energy-intensive sectors.

Yang et al. (2025) examined the effects of China's national carbon trading system (ETS) through a DID approach. The results showed which in the short term, regions highly dependent on energy-intensive industries experience a temporary decline in economic growth, whereas in the long term, ETS facilitates sustainable economic growth by encouraging innovation and improving energy efficiency. Furthermore, the success of ETS depends on careful policy design and attention to regional differences.

3.3. Studies on the impact of ETS on innovation and renewable energy

Ly & Bai (2021) evaluated the efficacy of the ETS regarding enterprise innovation using data from seven Chinese carbon trading pilot markets from 2013 to 2016. Findings displayed that implementing the ETS notably boosts enterprise innovation, that is, both ETS price and its volatility affect enterprise innovation productively, showing its effectiveness. Moreover, considering the combined impact from enterprise innovation and ETS, the firm performance of enterprises experiences negligible negative shocks.

Huang et al. (2023) investigated how emissions trading schemes influence renewable energy development in China. The research applied the CEEEA2.0 framework, an equilibrium-based analytical model that, like various other CGE analyses, incorporates both equilibrium theory and input-output analysis. The results indicate that introducing carbon trading reduces the price gap between renewable and fossil energy, which encourages a shift toward renewable sources. Moreover, the study found that such trading significantly decreases coal's proportion and increases the total share of renewable energy.

Jia et al. (2024) examined the influence of carbon emissions trading pilot schemes on shifts in the macro-level energy consumption structure, applying the difference-in-differences (DID) method. Drawing on panel data from 30 provinces in China spanning 2007 to 2020, their research found that the introduction of these pilot schemes significantly accelerated adjustments in regional energy usage patterns. This was evident through the dual shift from coal to oil and gas, as well as from fossil fuels to non-fossil energy sources. The policy led to significant decreases in both overall carbon emissions and emission intensity in the pilot areas. In addition, enhanced green finance in the provinces participating in carbon trading pilots had a marked effect on lowering carbon emissions. Overall, the implementation of carbon emissions trading produced notable improvements in optimizing the energy consumption structure, largely attributable to strengthened environmental regulations.

3.4. Comparative studies between ETS and other emission reduction policies

Li & Jia (2017) conducted a study using a CGE model to determine the most effective strategy for addressing climate change in China. In this study, 17 scenarios were implemented to lower CO₂ emissions. The results depict that CO₂ emissions in 2030 will be reduced by 10-13%, 12-14%, and 18-28% by implementing the carbon tax policy, the ETS, and a combination of both policies, respectively. Thus, the combined policy has more significant impacts on reducing primary energy consumption, resulting in CO₂ emissions that peak before 2030 and the peak emission not exceeding 12 billion tons.

Xu et al. (2023) addressed the results of two policies carbon tax and carbon emissions trading, in China by computable general equilibrium model. The findings showed that for economic development, carbon emissions trading is more effective than a carbon tax, and for emission reduction, a carbon tax is superior to carbon emissions trading.

Zhang & Lin (2024) measured the impact of China's two certified emission reduction (CCER) and Cap and Trade schemes in the ETS framework via a CGE model. The findings indicate the Cap and Trade mechanism can have positive effects on China meeting its carbon reduction targets but providing limited assistance to renewable energy generation. Nevertheless, the unique certified emission reduction mechanism of China chiefly elevates the generation of renewable energy sectors and cuts their prices, spilling over to other energy-consuming sectors, as a result, helping to mitigate the decline in GDP and residential welfare.

Jia et al. (2025) conducted a study using a CGE model to analyze the effects of combining carbon emission trading and carbon tax policies in China. The results showed that implementing these two policies simultaneously leads to greater reductions in carbon emissions than adopting either policy individually, while also imposing lower economic costs. Furthermore, it contributes to the optimization of the energy structure and reduces the intensity of energy-related emissions.

3.5. Differences in approaches and methods used in previous studies

Previous studies have employed diverse approaches to examine the effects of carbon emissions trading policies. Most of these studies have utilized computable general equilibrium (CGE) models (e.g., Meng et al., 2018; Lin and Jia, 2019; Huang et al., 2019; Nong et al., 2020; Li and Jia, 2017; Xu et al., (2023); Zhang & Lin, 2024; Jia et al., 2025) to analyze the macroeconomic and environmental impacts of emissions trading systems (ETS). In contrast, some more recent studies have employed the difference-in-differences (DID) approach to empirically assess the actual impact of ETS on emissions and the energy structure (e.g., Hou et al., 2024; Xu et al., 2025; Yang et al., 2025; Jia et al., 2024). Moreover, more advanced models, such as GTAP-E-POWER-S and CEEEA2.0, have been employed, combining the general equilibrium and input-output approaches (e.g., Han et al., 2023; Huang et al., 2023).

According to the studies above, currently, research on carbon markets has been carried out in several countries. International research concentrates mostly on the economic and environmental benefits of carbon trading policies and argues that establishing a carbon market, not only incentivizes polluting entities to reduce greenhouse gas emissions from their activities, but also fosters and promotes business, employment, and income generation for a certain segment of society. However, due to the growing trend of carbon dioxide emissions in Iran, the carbon market in it has not been examined using CGE models. Therefore, to address the identified research gap, the implementation of a regional carbon market between Iran and some of its trading partners has been conducted using the GTAP-E-Power-S model, in which the structure of the carbon market has been redesigned to better assess climate change-related policies. Also, emission levels of other pollutants in addition to carbon dioxide have been added to the model. Besides,

we investigated an important indicator called structural changes because of the implementation of the carbon market in this study.

4. Methodology

4.1. Experimental model of research

The GTAP model operates as a static framework and therefore does not reflect the dynamic effects of technological change, population growth, or changes in capital stock. Its mathematical formulation consists of a set of nonlinear equations derived from microeconomic maximization theory using the Dugan method, together with accounting relationships. This model was introduced by [Thomas Hertel \(1997\)](#) and because the design of the GTAP model requires a considerable number of economic elements, it is not easy to state a general concept of the theoretical foundations of this model as a result, at first, [Hertel \(1997\)](#) ignores the role of the government and the external sector in describing this model to facilitate understanding of the related concepts related. The GTAP-E model, as an extension of the GTAP, model was designed to analyze the impacts of climate change policies internationally. The difference between this model and the Hertel model is that the capital-energy composite input is incorporated into the production structure and carbon emissions from fossil fuel combustion are viewed as an input into the production process for producers in region r or as an output from the consumption of goods by private and public households ([Burniaux & Truong, 2002](#); [Nijkamp et al., 2005](#)). The only distinction between the GTAP-E model and its basic form is considering the energy factor and including carbon dioxide emissions from fossil fuels by [Burniaux & Truong \(2002\)](#), enabling the evaluation of environmental policies. The electricity sector in GTAP-E has been replaced by a commodity called the electricity virtual commodity in GTAP-E-Power. This commodity is a combination of transmission, distribution, nuclear power, coal, gas consumption for electricity generation during both peak and off-peak electricity consumption, oil consumption during peak and off-peak electricity consumption, hydroelectric energy while peak and off-peak, electricity generated from wind, sunlight, and other electricity generation technologies ([Peters, 2016](#)). [Nong \(2020\)](#) introduces the GTAP-E-PowerS model (which is a generalization of the GTAP-E-Power model). In this model, the carbon market structure has been redesigned to evaluate climate change-related policies more precisely. To result more accurately, besides carbon dioxide, emission levels of other pollutants have been added to the model, correcting the underestimation of the impacts of climate change policies. Considering pollutants other than CO₂, every sector of the economy faces greater expenses associated with their emission outputs. This scenario imposes a heavier financial burden on the entire economy than when only CO₂ emissions are taken into account.

In the GTAP-E and GTAP-E-Power models, calculations are limited to carbon dioxide emissions produced by fossil fuel combustion. For a more comprehensive assessment, it is crucial to also account for emissions arising from coal and gas extraction and transportation, greenhouse gases generated by industrial processes,

emissions associated with land use and livestock in the agricultural sector, and those stemming from chemical consumption. Additionally, by modifying the carbon market structure in the GTAP-E-Power model, it becomes possible to apply a carbon price to emissions generated by a range of sectors, including industry, households, and government. The GTAP-E-(Power-S) model builds upon the generation and consumption frameworks established in the GTAP-E-(Power) model. Figure 1 offers a detailed illustration of the electricity sector configuration in both models.

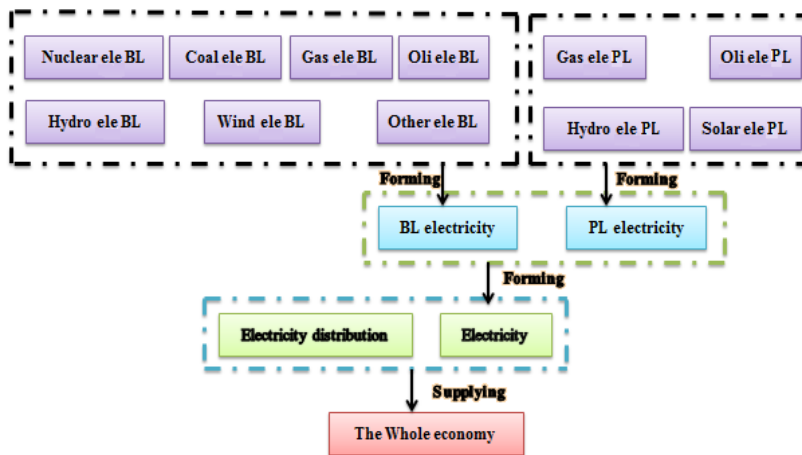


Figure 1. Electricity generation structure in the GTAP-(E-POWER) and GTAP-(E-POWER-S) models.

Source: Nong (2020)

Electricity is generated using two distinct technologies: base-load and peak-load. The base-load electricity mix consists of seven different commodities, each determined by its respective price. A similar pricing system defines the composition of the peak-load electricity mix. Since base-load and peak-load electricity are used for different purposes—such as meeting demand at certain times of the day or during specific seasons—these two composite commodities cannot be substituted for one another. In other words, both base-load and peak-load electricity are used to meet regular electricity demand, with no substitution between them. Moreover, the demand for electricity parallels the demand for electricity transmission and distribution services.

Figures 2 and 3, respectively, illustrate the mechanisms related to the carbon market in the GTAP-E-Power and GTAP-E-PowerS models.

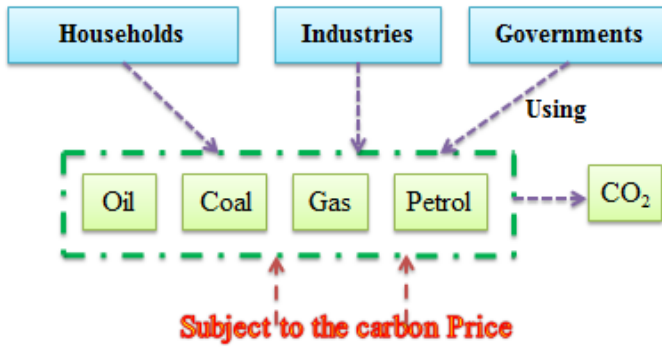


Figure 2. Carbon market modeling within the GTAP-(E-POWER) model

Source: Nong (2020)

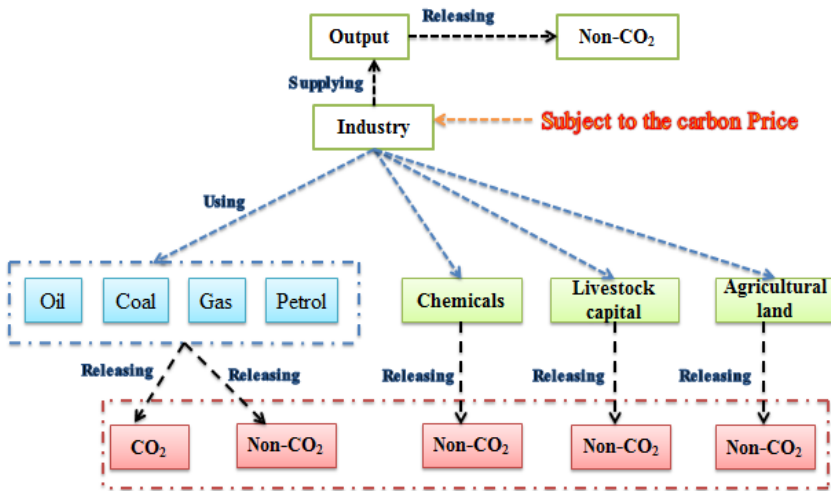


Figure 3. Carbon market modeling within the GTAP-(E-POWER-S) model

Source: Nong (2020)

In the GTAP-E-Power model, fossil fuels are subject to a carbon price, so all emissions from their use—whether by the private or public sector—are covered by carbon pricing. This approach lacks flexibility, as every industrial sector is included in the carbon tax or emissions trading scheme, with no option for exempting specific industries.

The GTAP-E-Power-S model, however, adopts a different approach by assigning the carbon tax to industries rather than to fossil fuel commodities. This adjustment makes the system more flexible and practical compared to the GTAP-E-Power model. The carbon tax or emissions trading scheme in this model can set a price for carbon generated by industries from selected emission sources—such as

fossil fuel combustion, chemical consumption, manufacturing processes, or from all sources collectively.

4.2. Total CO₂ emission equation

Equation (1) generally expresses that total carbon emissions arising from the use of energy input e in region z are obtained as a weighted average of the following elements:

$$\begin{aligned} CO_2(e, z) * gco_2(e, z) = & sum(y, PROD, CO_2_IMF(e, y, z) * gco_2_imf(e, y, z) \\ & + CO_2_DCF(e, y, z) * gco_2_dcf(e, y, z)) \\ & + CO_2_DGV(e, z) * gco_2_dgv(i, r) + CO_2_IGV(e, z) * gco_2_igv(e, z) \\ & + CO_2_DHH(e, z) * gco_2_dhh(e, z) + CO_2_IHH(e, z) * gco_2_ihh(e, z) \end{aligned} \quad (1)$$

In this equation, e is: energy e^{th} input, y is: y sector and z is: z region.

$CO_2(e, z)$: The total carbon emissions associated with the e^{th} energy input in region z , $gco_2(e, z)$: The growth rate of total carbon emissions associated with the e^{th} energy input in region z .

CO_2_DCF : Carbon emissions resulting from firms' domestic demand for goods, CO_2_IMF : Carbon emissions from imported demand for goods by firms.

CO_2_DGV : Carbon emissions from government demand for domestic goods, CO_2_IGV : Carbon emissions from government demand for imported goods.

CO_2_DHH : Carbon emissions from household demand for domestic goods, CO_2_IHH : Carbon emissions resulting from households' demand for imported goods.

$PROD$ shows the set of manufactured goods.

gco_2_dcf : The growth rate of carbon emissions associated with firms' demand for domestic goods, gco_2_imf : The growth rate of carbon emissions associated with firms' demand for imported goods.

gco_2_dgv : The growth rate of carbon emissions associated with the government's demand for domestic goods, gco_2_igv : The growth rate of carbon emissions associated with the government's demand for imported goods.

gco_2_dhh : The growth rate of carbon emissions associated with households' demand for domestic goods, gco_2_ihh : The growth rate of carbon emissions associated with households' demand for imported goods.

It is further assumed that the growth rate of demand for the e^{th} energy input in sector y and region z matches the growth rate of carbon emissions from the same energy input in sector y and region z .

$$gco_2fd(e, y, z) = qfd(e, y, z) \quad (2)$$

4.3. Emissions Permits and Emissions Trading

One method of the emissions trading system is the Cap and Trade. The first principle is the cap or limitation used in emissions trading, and each institution

(country or company) has a specific cap on carbon emissions. The second principle is trading, creating a market to exchange carbon emission permits. In other words, entities implementing this policy can trade their emission permits in the carbon trading market. At the end of the specified period, entities that exceed their emission limit can purchase carbon credits from entities with a surplus in their emission limit. The emissions trading scheme can be implemented at the domestic, regional, and global levels. This study divides the world into 6 regions: Iran, trading partners (China, Turkey, India, and the United Arab Emirates), and the rest of the world. The variable $gco2q$ represents the percentage change in carbon dioxide emission quotas, while $gco2t$ denotes the percentage change in carbon dioxide emissions. A regional carbon market is set up between Iran and trading partners, and they exchange carbon emission permits with each other. Therefore, countries entering the carbon market are placed in one block and other regions that are not active in the carbon market are placed in a different block.

4.4. Net income from Emission Trade; regional income

The income is calculated from, first, the imposition of a carbon tax, and second, the purchase and sale of carbon emission permits using the following equation:

$$\begin{aligned} DVCO_2TRA(z) = & CO_2_Q(z) * NC_TAX(z) * 0.01 * gco_2_q(z) \\ & - CO_2_T(z) * NC_TAX(z) * 0.01 * gco_2_t(z) \\ & + [CO_2_Q(z) - CO_2_T(z)] * NC_TAXB_ (REGTOBLOC(z)) \end{aligned} \quad (3)$$

The equation components are:

$DVCO_2TRA$: Net revenue from carbon emissions trading

CO_2_Q : Carbon dioxide emission quota

CO_2_T : Total carbon dioxide emissions

gco_2_q : Percentage change in carbon dioxide emission quota

gco_2_t : Percentage change in carbon dioxide emissions

NC_TAX : Nominal carbon tax rate

$NC_TAXB_ (REGTOBLOC(z))$: Represents a block correspondence, so that countries entering the carbon market are placed in one block and other regions in a different one.

The variable $DTBALCTRA$ indicates the trade balance and has two parts: $DTBAL$ is the net flow of export value and $DVCO_2TRA$ is the net income from carbon emissions trading.

$$DTBALCTRA(z) = DTBAL(z) + DVCO_2TRA \quad (4)$$

In the equation (5) shows the components of regional household income, including income from the supply of primary factors of production (FY), income from indirect taxes, income from carbon taxes, and net income from carbon emissions trading.

$$INCOME(z) * y(z) = FY(z) * fincome(z) \quad (5)$$

$$+ 100.0 * INCOME(z) * del_indtaxr(z)$$

$$+ IND TAX(z) * y(z)$$

$$+ 100.0 * DV CO_2 TRA$$

$$+ 100.0 * sum\{e, CTAX_COM, VCTAX(z, e)\}$$

$$+ INCOME(z) * incomeslack(z)$$

$INCOME(z)$: Regional household income

$y(z)$: Regional household income growth rate

$FY(z)$: Income from the supply of primary factors of production

$fincome(z)$: The growth rate of income from the supply of primary factors of production

$del_indtaxr$: Change in indirect taxes

$IND TAX$: Total indirect taxes

$CTAX_COM$: Energy inputs that are subject to taxation

$VCTAX$: The monetary value of carbon tax

$incomeslack$: An auxiliary exogenous variable that can be used to define a scenario for changing regional household income.

4.5. Dynamic block

4.5.1. capital accumulation

At this stage, the temporal behavior described for the GDyn system of equations can be applied. First, the capital accumulation equation is employed, drawing on the capital stock variable from investment theory and financial asset theory. The integral equation that defines the capital stock can be formulated as follows:

$$K(z) = K_0(z) + \int_{T_0}^T INV K(z) d\tau \quad (6)$$

In this equation $K(z)$, denotes the capital stock specific to region z , $K_0(z)$ refers to capital stock in the initial period T_0 , and T indicates the current period, and $INV K(z)$ represents net investment. Differentiating this equation yields:

$$K(z) \frac{gK(z)}{100} = INV K(z).time \quad (7)$$

In this context, $gK(z)$ indicates the percentage change in capital stock for region z , and the variable $time$ indicates the temporal variation. When both sides of the equation are multiplied by one hundred times the price of capital goods, the following equation results:

$$VK(z).gK(z) = 100VINVK(z).time \quad (8)$$

Here, $VK(z)$ indicates the monetary worth of capital stock in region z , while $VINV K(z)$ refers to the monetary amount of net investment. Under a static simulation setting, where all temporal variations are considered zero, Equation (8) demonstrates that $gK(z)$, the percentage change in capital stock, is likewise zero. Nonetheless, it is possible to introduce certain non-zero modifications to capital stocks. For this purpose, a global adjustment factor, SWRLD, along with a region-

specific adjustment factor, $SREG(z)$, are included in the accumulation equation. Incorporating these elements yields the final form of the equation as follows:

$$K(z) = SWRLD.SREG(z) \left[K_0(z) + \int_{T_0}^T VINVK(z) dT \right] \quad (9)$$

The differential equation is expressed as follows:

$$VK(z).gK(z) = VK(z)[swrld + sreg(z)] + 100VINVK(z).time \quad (10)$$

4.5.2. asset accumulation

The portfolio of financial assets consists of two principal variables: the value of firm ownership and household stock holdings in region z . Each of these is determined, either directly or indirectly, through the mechanisms of accumulation. Within the GDyn framework, firms acquire intermediate inputs, employ labor, and lease land, yet they are the proprietors of fixed capital. They do not incur liabilities and have no assets apart from fixed capital. Consequently, the firm ownership value in region z , represented as $OWN_F(z)$, corresponds to the value of their fixed capital—this reflects the entire local fixed capital and is obtained by multiplying its price by its quantity.

$$OWN_F = VK(z) = CAPPR(z) . K(z)$$

In this context, $CAPPR(z)$ specifies the price for capital goods in region z . As a result, the total equity value of firms in each region is determined indirectly through the capital accumulation equation (Equation 10). It should be noted that the share price of firms in region z is proportional to the price of capital goods within the same region.

$$pr_f(z) = cappr(z) \quad (11)$$

where pr_f denotes the percent variation in $PR_F(z)$. The variable time serves to reflect the inherent dynamics of wealth and savings within each region. An accumulation equation is also defined for the ownership of domestic household assets at the regional level.

$$HHOWN(z) = PR_F(z) \int_{T_0}^T HQSH(z) dT \quad (12)$$

where $PR_F(z)$ indicates the equity price of local firms in region z , and $HQSH(z)$ refers to the quantity of shares acquired by the regional household. In a similar manner, for the regional household's equity in the Global Trust, the following relationship can be written:

$$HHOWNTRUST(z) = PRTRUST \int_{T_0}^T HQSHTRUST(z) dT, \quad (13)$$

where $PRTRUST$ specifies the equity price within the Global Trust, and $HQSHTRUST(z)$ indicates the volume of shares acquired by the regional household. The aggregate wealth of the regional household is obtained by adding together these two equations.

$$HHW(z) = HHOWN(z) + HHOWNTRUST(z) \quad (14)$$

Through differentiation and replacement of $pr_f(z)$ using Equation (11), the resulting equation is derived:

$$HHW(z).hhw(z) = HHOWN(z).cappr(z) + HHOWNTRUST(z).prtrust + 100(HHINVF(z) + HHINVTR(z))time \quad (15)$$

New investment arising from the regional household's equity in domestic firms within region z , represented by $HHINVF(z)$, as well as that resulting from its equity in the Global Trust, denoted by $HHINVTR(z)$, is determined by multiplying the equity price—whether for local firms or the Global Trust—by the number of shares purchased by the household.

The sum of the regional household's new investments in both domestic and international equities corresponds to its total savings, that is: $HHINVF(z) + HHINVTR(z) = HSAVE(z)$. Therefore, Equation (15) is simplified.

$$HHW(z).hhw(z) = HHOWN(z).cappr(z) + HHOWNTRUST(z).prtrust + 100.HSAVE(z).time \quad (16)$$

4.5.3. Firms' and households' assets and liabilities

In this subsection, firm shares are categorized into those held by the local household and those held by the Global Trust. Similarly, the wealth generated from regional households' equity is apportioned between shares in local firms and shares in the Global Trust. The equity of firms within a region is made up of two elements: shares owned by the local regional household, $HHOWN(z)$, and shares held by the Global Trust, $HTRUST(z)$. Thus, the following equation is established:

$$OWN_F(z) = HHOWN(z) + HTRUST(z) \quad (17)$$

By differentiating, the following equation is obtained:

$$OWN_F(z).ow_f(z) = HHOWN(z).hhow(z) + HTRUST(z).htru(z) \quad (18)$$

Within this context, $hhow(z)$ together with $htru(z)$ indicate the respective percentage variations in $HHOWN(z)$ and $HTRUST(z)$.

The wealth derived from regional household equity, denoted by HHW , is classified into two categories: $HHOWN$, representing shares in regional domestic firms, and $HHOWNTRUST$, representing shares in the Global Trust.

$$HHW(z) = HHOWN(z) + HHOWNTRUST(z) \quad (19)$$

By differentiating, the following equation is obtained:

$$HHW(z).hhw(z) = HHOWN(z).hhow(z) + HHOWNTRUST(z).hhtr(z) \quad (20)$$

where $hhow(z)$ and $hhtr(z)$ represent the percentage changes in $HHOWN(z)$ and $HHOWNTRUST(z)$, respectively.

So far, for each region, Equations (15) and (17) are present, together with three variables: $HHOWN(z)$, $HTRUST(z)$, and $HHOWNTRUST(z)$, which need to be determined. Equivalently, for each region, there are sufficient conditions to establish the net value of foreign assets, while the gross values of both foreign assets

and liabilities—namely, $HHOWNTRUST(z)$ and $HTRUST(z)$ —cannot be uniquely identified.

$$HHOWNTRUST(z) - HTRUST(z) = HHW(z) - OWN_F(z) \quad (21)$$

In this model, due to the absence of portfolio allocation theory, the position of gross asset ownership cannot be explicitly determined; investors focus solely on returns, and in the long run, with equal capital returns across regions, asset allocation becomes discretionary.

4.5.4. Global trust assets and liabilities

Three accounting relationships are associated with the global trust. Firstly, the value of assets held by the global trust, $HOWNTRUST$, is determined as the sum of foreign ownership in firms across all regions:

$$HOWNTRUST = \sum_r HTRUST(z) \quad (22)$$

Its percentage change is given as follows:

$$HOWNTRUST.how = \sum_r HTRUST(z).htru(z), \quad (23)$$

In this context, *how* represents the percentage variation in $HOWNTRUST$. Following the second identity, the trust value, $HOWN_TRUST$, is calculated as the aggregate of regional shares in the trust, which essentially corresponds to the total foreign ownership of assets among the regions:

$$HOWN_TRUST = \sum_r HHOWNTRUST(z); \quad (24)$$

Its percentage change is given as follows:

$$HOWN_TRUST.h_tr = \sum_r HHOWNTRUST(z).hhtr(z),$$

Here, *h_tr* represents the percentage change in $HOWN_TRUST$. Ultimately, the overall trust value corresponds to the total worth of its assets.

$$HOWN_TRUST = HOWNTRUST$$

This equation is considered redundant within the model since it is cited in other expressions. The accumulation relations, along with the equivalence of global investment and global savings, guarantee that the total value of physical capital consistently matches the total value of financial asset holdings across all regions.

$$\sum_r OWN_F(z) = \sum_r HHW(z) \quad (25)$$

Based on Equations (21), (22), (32), (24), and (25), it can be demonstrated that:

$$HOWN_TRUST = HOWNTRUST$$

The following equation is added to the model to ensure that the simulation results comply with the given identity:

$$HOWNTRUST = HOWNTRUSTSLACK.HOWN_TRUST,$$

where *HOWNTRUSTSLACK* is an exogenous variable. In its percentage change form:

$$how = h_{tr} + howntrustslack \quad (26)$$

Here, *howntrustslack* represents the percentage variation in *HOWNTRUSTSLACK*. In a manner analogous to Equation (23), which defines asset values, a corresponding price equation is formulated. The growth of assets and ownership can be separated into components of investment and capital gains. For the global trust, aligning the capital gain elements of assets and ownership results in the following relationship:

$$\begin{aligned} prtrust &= \sum_r \frac{HTRUST(z)}{HOWNTRUST} cappr(z) \\ &= \sum_r HOWNTRUSTSHR(z).cappr(z) \end{aligned} \quad (27)$$

HOWNTRUSTSHR(z) represents the equity share of region *r* in the total assets of the global trust.

4.6. Data and aggregations

Following the research methodology described, the data used in this paper are divided into three parts. The first part includes the data used in the dynamic general equilibrium model focusing on the environment and the carbon market, which is available in the GTAP version 10 database. This data involves the social accounting matrix of 141 countries (or regions), 65 sectors, and 8 primary factors of production in 2014. To this, GTAPagg software is included with the GTAP database, used to aggregate data for use in general equilibrium models. The data has been aggregated based on the research objective in the form of 13 sectors: agriculture, coal, oil, gas, petroleum products, electricity distribution and transmission, electricity from renewable energies with peak load, electricity from renewable energies with base load, electricity from fossil energies with peak load, electricity from fossil energies with base load, energy-intensive industries, other industries, and the services sector; 5 factors of production: land, capital, natural resources, skilled labor, and unskilled labor; 6 regions: Iran, major trading partners (China, Turkey, the United Arab Emirates and India) and other countries. The second part is the problem parameters (used in various goods' production and consumption functions). The third section presents the forecast data. Variables including gross domestic product, population, primary factor supply, carbon emissions, and energy consumption are sourced from the CEPII database, compiled by (Fontagné et al., 2022).

4.7. Scenarios

The research considers two types of scenarios: baseline and policy. Taking 2015 as the reference year, the baseline scenarios are formulated based on projected growth trends in variables such as GDP, population, and the supplies of skilled and unskilled labor. In other words, under these baseline projections, a carbon market is established for six regions over the 2015–2050 horizon.

In this study, some numbers were considered targets for Iran and trading partners (China, India, Turkey, and the United Arab Emirates) for the policy scenarios, and under the goal, a quota amount was chosen for each country. For China, this number was extracted from the study by [Huang et al. \(2019\)](#); for India from the study of [Gambhir et al. \(2014\)](#), and for Turkey from the study by [Kat et al. \(2018\)](#). The number for the United Arab Emirates is, according to COP 28, committed to diminishing carbon emissions by 90% by 2050; for Iran, it is assumed that it would cut carbon emissions by 25% to 2050.

5. Experimental results

This section examined the impact of the carbon market on Iran's environmental performance, income, structural changes, and gross domestic product. Furthermore, for the structural change index, the variance between the production growth rate of each sector and the growth rate of gross domestic product was used, in which a negative number is a decrease in the share of the sector and a positive number is an increase in the share of the sector in production. Thus, the experimental results of the scenarios are divided into four sections.

5.1. The impact of emission trading on environmental performance

Table 2 and Fig. 4 display the real performance of each country. The carbon emissions trading system specifically focuses on carbon dioxide reduction goals, so according to the results, establishing the carbon emissions trading system shrinks CO₂ emissions, evidencing that this system is a potent tool to reduce CO₂ emissions. For the countries under study, we can observe a CO₂ downward trend that is different in each country. The CO₂ emission reduction in Iran in 2015 was 1.45 percent and is projected to reach 40.29 percent by 2050. According to the model output, Iran and China performed well in achieving the target, while India, Turkey, and the UAE did not reach their carbon emission reduction targets.

Table 2. The impact of emission trading on CO₂ emission (%change)

gco _{2t} (D)	2015	2020	2030	2040	2050
China	-2.27	-12.72	-27.58	-34.06	-40.22
India	-1.03	-5.67	-22.26	-34.07	-43.04
Iran	-1.45	-9.42	-25.52	-32.99	-40.29
Turkey	-0.9	-6.3	-18.44	-23.61	-29.06
EMA	-1.02	-6.3	-18.16	-25.16	-34.15

Source: Simulation Results

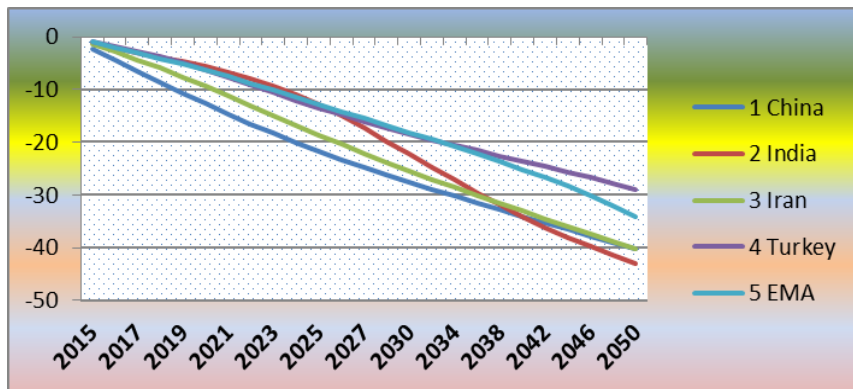


Figure 4. The impact of emission trading on CO₂ emission (%change)

Source: Simulation Results

5.2. The impact of emission trading on income of carbon market

Figure 5 and Table 3 depict the impact of the carbon market on the income of Iran and its trading partners between 2015 and 2050. Iran's income in 2015 was \$4.18 million and is projected to gain an income of \$10,162.89 million by 2050. This amount is equivalent to 1.43% of Iran's GDP, which is considerable compared with other government income sources. Positive or negative income can be analyzed based on the quota set and each country's performance. The number of permits is allocated according to the amount of commitment to reduce emissions of each country, and during the commitment period, the countries can trade these permits. Thus, the countries with a more significant share of their carbon dioxide emissions than their permitted limit must buy more emission rights, and countries with lower carbon emissions sell their carbon emission rights to other countries. Therefore, accordingly, the countries of China and Iran earned positive income by selling these permits due to the lower carbon emissions than the quota. The countries of India, Turkey, and the UAE had higher carbon emissions than the quota set for them and had to buy permits leading them to negative income.

Besides, according to the calculation of the maximum value for Iran and its carbon emission quota, if this country is required to lessen carbon emissions by 1.8% annually, it can earn positive income.

Table 3. The impact of emission trading on income of carbon market (Million \$dollars, % of GDP)

2015	2020	2030	2040	2050
------	------	------	------	------

DVCO2T RA (D)	Milli on \$doll ars	% of GD P	Millio n \$dollar s	% of GD P	Millio n \$dolla rs	% of GD P	Millio n \$dolla rs	% of GD P	Millio n \$dolla rs	% of GD P
China	117.58	0.01	5390.44	0.043	41449.76	0.194	73565.29	0.273	117493.6	0.368
India	-92.63	0.05	4384.04	0.155	35101.7	0.744	62317.11	1.011	100516	1.252
Iran	4.18	0.01	310.97	0.066	3155.33	0.611	5852.79	0.957	10162.89	1.432
Turkey	-3.88	-	-	-	-	-	-	-	-	-
		0.00	154.41	0.019	711.959	0.089	1470.42	0.162	2335.82	0.223
EMA	-25.29	0.07	1162.12	0.280	8789.70	2.020	15628.9	3.455	24802.9	5.435

Source: Simulation Results

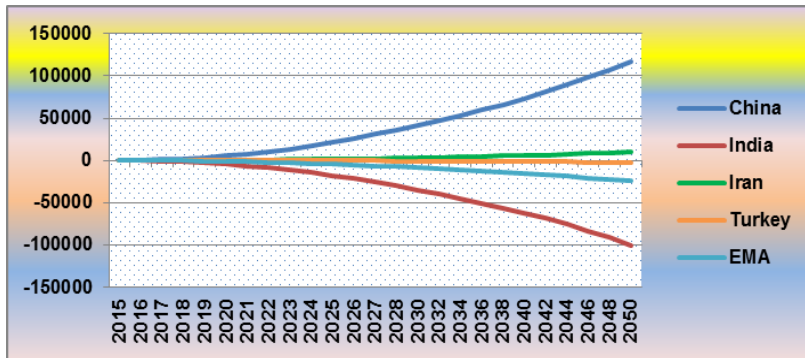


Figure 5. The impact of emission trading on income of carbon market (Million \$dollars)

Source: Simulation Results

5.3. The effect of carbon market trading on structural changes

Table 4 shows the production share of each sector. According to the statistics in version 11 of the GTAP database, Iran emits 0.2 kg of carbon dioxide for each unit of production in the agricultural sector. This number is lower than the FBL, energy-intensive industries, other industries, and services sectors. The FBL sector emits approximately 60 times, the energy-intensive industries sector 6 times, the other industries sector 1.16 times, and the services sector 2 times as much as the agricultural sector does. Also, the Iranian energy balance sheet for 2020 evidenced that the total carbon dioxide emission in Iran was 667,967,917 tons, and the share of each sector was as follows: the power plant sector 29.95 percent, the household, commercial, and public sector 24.39 percent, the transportation sector 21.19 percent, the industry sector 19.14 percent, and the agricultural sector 2.64 percent.

Hence, the agricultural sector has small-scale carbon emissions, as a result, the share of this sector has not decreased while launching the regional carbon market. Electricity generation is from different sources and carriers and uses different methods. The foremost method of electricity generation is by thermal power plants utilizing fossil fuels; in Iran, more than 90 percent of electricity generation is generated from these power plants. Fossil fuels are one of the main reasons for carbon dioxide emissions, and the emission of this gas from these power plants hurts the environment. These environmental threats have made societies use alternative sources of energy instead of conventional energy forms. Therefore, renewable energy sources have emerged as a crucial component of world energy consumption, and their key feature is decreasing carbon dioxide emissions and helping to protect the environment. The carbon market is a vital tool to reduce carbon. Under this policy, allowing for the purchasing and selling of permits, it capably sets a price for carbon emissions. By increasing the cost of carbon emissions, fossil-fuel-based energy becomes relatively more expensive compared to renewable alternatives, and based on the price of carbon emissions, firms can motivationally move towards renewable energy technologies with lower or zero emissions associated with their operations. The results obtained in 2015 indicate a decrease in the share of the FBL sector in Iran by 0.85% and is expected to decrease by 15.79% by 2050. In 2015, the increase in the share of the RBL sector was 1.9% and is projected to reach 22.1% by 2050.

At the level of economic sectors, energy consumption is directly related to pollution levels. It can be said that the main reason for the increase in carbon dioxide emissions is the disproportionate expansion in the intensity of energy use and includes issues such as lack of technical efficiency, energy waste, lack of optimal use, etc. Iran has a key role in energy in the world, but statistics reveal the inefficient and excessive use of these energy resources. In the energy-intensive industries sector, the high share of energy costs and carbon emissions and the increase in the cost of purchasing emission permits will lead to a steady decrease by 2050 in this sector, and the maximum decrease will be 7.13 percent. As a result, non-energy-intensive industries will replace energy-intensive industries. The service sector share will also constantly decrease by 2050, but this decrease is not as significant as the share of energy-intensive industries. Moreover, the growth of the oil sector's share increases from 0.1 percent to 1.79 percent, showing the fact that Iran's economy remains dependent on oil during the simulation period.

Table 4. emission trading an structural changes (%change)

Iran	2015	2020	2030	2040	2050
Agricultural	-0.08	-0.21	0.35	0.84	2.06
Oil	0.1	0.63	1.18	1.21	1.79
petroleum products	-0.27	-1.48	-2.06	-1.38	-0.61
electricity generated from	1.9	9.57	16.58	19.21	22.1

renewable energies with base load (RBL)					
electricity generated from fossil fuels with base load (FBL)	-0.85	-5.37	-12.25	-13.85	-15.79
energy-intensive industries	-0.47	-2.69	-7.6	-7.32	-7.13
other industries	-0.2	-1.24	-2.19	-1.17	-0.51
services	-0.06	-0.45	-1.29	-1.74	-2.65

Source: Simulation Results

5.4. The effect of the carbon market on GDP

Table 5 shows the GDP of Iran and its trading partners by 2050. GDP has a downward trend, and its amount varies in countries. Iran experienced a decrease of 0.01 percent in 2015 and is expected to decrease by a maximum of 3.33 percent by 2050. A considerable part of Iran's economy is energy-intensive, so while implementing the carbon market, the additional cost of emissions will increase production costs and lead to limitations in production, so the GDP will decrease.

Table 5. The effect of the carbon market on GDP (%change)

Qgdp (D)	2015	2020	2030	2040	2050
China	-0.03	-0.56	-2.22	-2.63	-2.09
India	-0.03	-0.53	-2.7	-3.48	-3.53
Iran	-0.01	-0.56	-2.18	-2.58	-3.33
Turkey	-0.02	-0.22	-1.22	-2.11	-3.34
EMA	-0.01	-0.21	-1.92	-4.21	-8.13

Source: Simulation Results

6. Systematic Sensitivity Analysis

In studies using computable general equilibrium (CGE) models, sensitivity analysis is considered a key tool for evaluating the robustness of results against parametric uncertainties. In this study, a systematic sensitivity analysis was conducted, in which three key parameters—Armington elasticity, primary factor substitution elasticity, and capital-energy substitution elasticity—were varied individually over a range from 0.5 to 2 times their baseline values. For each parameter, the mean, standard deviation, and confidence interval were calculated based on values within this range. The confidence interval was defined using Chebyshev's inequality at a 95% confidence level, resulting in bounds approximately equal to “mean $\pm$ 4.7 $\times$ standard deviation.” The results were considered statistically valid if two conditions were met: first, the obtained value fell within the confidence interval; and second, the confidence interval did not change its sign. Based on the sensitivity analysis, variations in the elasticity parameters did not significantly affect the trends or directions of the results. Key

model outputs—including gross domestic product, carbon dioxide emissions, and energy intensity—remained within the valid confidence interval range. Therefore, the statistical evidence indicates that the results and analyses are sufficiently robust to serve as a reliable basis for policy-oriented conclusions.

Table 6. Sensitivity Analysis

Sensitivity analysis results for a number of variables							
macroeconomic variables		2025			2050		
		Armingt on elasticit y	primary factor substituti on elasticity	capital- energy substituti on elasticity	Armingt on elasticit y	primary factor substituti on elasticity	capital- energy substituti on elasticity
gross domest ic product	mean	-0.011	-0.01	-0.015	-3.36	-3.33	-3.4
	standard deviatio n	0.0025	0.0021	0.0019	0.67	0.64	0.59
	confide nce interval	-0.022, 0.000	-0.019,- 0.000	-0.023,- 0.006	-6.509,- 0.211	-6.338,- 0.322	-6.173,- 0.627
	mean	-1.43	-1.38	-1.32	-40.29	-41.4	-39.11
carbon dioxide emissio ns	standard deviatio n	0.24	0.21	0.2	7.9	8.05	6.98
	confide nce interval	-2.558,- 0.302	-2.367,- 0.393	-2.26,- 0.38	-77.42,- 3.16	-79.235,- 3.565	-71.916,- 6.304
	mean	-0.46	-0.43	-0.49	-5.55	-5.2	-5.8
	standard deviatio n	0.054	0.057	0.06	0.71	0.68	0.72
energy intensit y	confide nce interval	-0.713,- 0.206	-0.697,- 0.162	-0.772,- 0.208	-8.887,- 2.213	-8.396,- 2.004	-9.184,- 2.416

Source: Simulation Results

7. Discussion

A carbon market refers to a mechanism in which greenhouse gases, particularly carbon dioxide, are treated as tradable commodities, allowing producers of these gases to buy and sell emission permits. The purpose of establishing a carbon market is to reduce the costs of pollution control and encourage emission reductions by providing economic incentives. This market is typically implemented as an emissions trading system (ETS), in which a cap on total emissions is set, and permits equivalent to that cap are then allocated among countries or firms. This study examines the impact of the carbon emissions market policy on carbon dioxide emissions, revenue, gross domestic product, and changes in sectoral output shares in Iran's economy using a dynamic computable general equilibrium (DCGE) model. The results showed that implementing a carbon

emissions trading system (ETS) in Iran would reduce CO₂ emissions by 40.29% by 2050. Comparison with international studies indicates that the effect of ETS on emission reduction depends on the scope of industrial coverage, energy structure, and modeling approach: Meng et al. (2018) reported a 12% reduction in Australia, Hou et al. (2024) a 12.3% reduction in carbon intensity in China, and Xu et al. (2025) a 17.5% reduction in Chinese thermal power plants. In terms of energy structure, the share of fossil-based electricity generation in Iran is projected to decrease by approximately 15.79% by 2050, while the share of electricity from renewable energy increases by 22.1%. Energy-intensive industries experienced a maximum reduction of 7.13%, with non-energy-intensive industries subsequently replacing them. Huang et al. (2023) demonstrated that the implementation of ETS can raise the share of renewable energy by approximately 1–2% while decreasing reliance on coal. Jia et al. (2024) also reported an acceleration in the substitution of non-fossil energy in China; however, Zhang & Lin (2024) emphasized that ETS alone has a limited effect on renewable energy development, and complementary mechanisms such as CCER play a more significant role. Revenue from ETS for Iran is projected to reach approximately 10,162.89 million USD by 2050. Huang et al. (2019) showed that the expansion of ETS in China could raise carbon market revenues to USD 336 billion and maintain approximately USD 299 billion by 2050. Han et al. (2023) explained that China's primary objective is not to generate direct revenue, but rather to reduce domestic decarbonization costs and enhance emission flexibility. Yang et al. (2025) also emphasized the importance of using ETS revenues strategically — for instance, to subsidize renewable energy — in order to achieve long-term success and promote simultaneous economic development and emission reduction. In terms of GDP, the implementation of ETS in Iran led to a 3.33% reduction by 2050. In international studies, the GDP reduction varies depending on the coverage scope and energy structure: Lin & Jia (2019) reported a decrease of 0.19–1.44%; Nong et al. (2020) found a reduction of 4.57% under limited sectoral coverage and 1.78% under full industry coverage; and Han et al. (2023) observed a 0.79% decline, whereas Huang et al. (2019) reported a 3% increase in China. Yang et al. (2025) also indicated that ETS promotes sustainable economic growth by enhancing innovation and productivity.

The limitations of this study can be summarized as follows: the baseline scenarios used for projections were defined based on previous studies and national commitments, while for Iran, a hypothetical scenario was considered due to the lack of realization of international investments related to the country's Nationally Determined Contribution (NDC) program for greenhouse gas emission reduction. To improve the accuracy of projections, future studies could employ advanced methods such as neural networks and deep learning. In addition, the regions in this study were aggregated into six groups, which may introduce aggregation bias; therefore, future studies could provide more accurate analyses by adopting a finer regional disaggregation. Ultimately, the CGE model used in this study has its

strengths and limitations; however, other models such as DSGE and GVAR could also be employed to analyze this issue.

8. Conclusions and policy recommendations

Carbon emissions trading is one of the key policies emphasized by international organizations for reducing greenhouse gas emissions. This market-based policy has significant economic and environmental implications. The objective of this study was to analyze the economic and environmental impacts of implementing a carbon emissions trading system in Iran and some of its trading partners using a dynamic computable general equilibrium (DCGE) model. Within this framework, the carbon emissions market was established among selected countries, and its effects on CO₂ emissions, income from permit sales, GDP, and structural changes in the economy were examined up to the 2050 horizon. The findings indicate that implementing a carbon emissions trading policy in Iran could result in a 40.29% reduction in CO₂ emissions by 2050, while generating revenues of USD 10,162.89 million from the sale of emission permits. However, GDP decreased by approximately 3.33% over the same period. In terms of the energy structure, the share of electricity generation from fossil fuels is projected to decrease by 15.79% by 2050, while the share of electricity generation from renewable energy is expected to increase by 22.1%. Furthermore, the results indicate that the share of energy-intensive industries declined by 7.13%, whereas the oil sector's share rose by 1.79% and the services sector's share fell by 2.65%. These results indicate that implementing a carbon emissions market, while contributing to a significant reduction in CO₂ emissions, also leads to energy restructuring and changes the composition of sectoral shares in the economy. While this policy may negatively affect economic growth in the short term, in the long term, by strengthening productivity and promoting the development of renewable energy, it will pave the way toward sustainable, low-carbon growth.

Based on the research findings, the following policy recommendations are proposed:

First, establishing a carbon emissions trading market is crucial for optimizing the energy structure. Understanding the beneficial effects of carbon trading on energy efficiency, it is highly important to expedite the development of carbon trading markets in pilot regions or industries. The parliament and the government should support the implementation of this policy by enacting relevant laws and executive regulations. When formulating policies, the parliament and the government should consider both economic and environmental benefits simultaneously and in the long term, and implement support packages to compensate for the short-term costs according to different economic sectors.

Second, the government can invest the revenue from the sale of emission permits in the renewable energy sector, ultimately growth in the deployment of renewable energy helps to diversify energy sources and decarbonize the global energy system. The impacts of the GDP reduction caused by the implementation of the plan can be offset by investment in renewable energy.

Third, establishing a carbon market requires the constant support of the people and economic actors and constructive cooperation between them and the government. Transparency in policymakers' interaction with other stakeholders grants the system's long-term sustainability. Moreover, to implement this plan, determining the scope of the carbon emissions trading system in geographical areas and sectors needs to be investigated.

Fourth, since establishing a carbon market in the implementation stages requires ensuring sufficient capacity of market process actors, technical expertise and professional human resources in market formation must be considered.

Author contribution

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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Appendix A.

Since the main focus of this study is structural change—and by structural change we refer to changes in the share of output of different sectors relative to total gross domestic product—only the parts of the model representing production

are presented. The structural change index was measured using the difference between each sector's output growth rate (qo) and the growth rate of gross domestic product ($qgdp$). A negative value indicates a decline in the sector's share, whereas a positive value indicates an increase in its contribution to total output.

In the GTAP-E-POWER model, firms' production is organized hierarchically using a constant elasticity of substitution (CES) function, with each layer illustrating the relationships between inputs and outputs at a particular stage of the production process.

The structure starts with the top-level total output nest and sequentially consists of the intermediate goods nest, the value-added–energy nest, and, within the energy nest, a combination of electricity and non-electric energy inputs. Within the value-added–energy nest, capital inputs and the energy composite are treated as a combined unit, jointly contributing to the production function. Next, the electricity energy input is separated into renewable-based and fossil fuel-based electricity, while the non-electric energy input is split into coal and non-coal categories, with the non-coal category ultimately including oil, gas, and petroleum products. For each of these nests, input demand functions are obtained following the cost-minimization principle, under the assumption of a given elasticity of substitution. At some levels, for instance in the total output nest, the elasticity of substitution is assigned a value of zero, which effectively transforms the CES function into a Leontief structure. The variables in these equations are defined in terms of percentage changes relative to the base value (growth form).

A.1.Total output nest

$$qf_{rzy} = qo_{zy} + ESVA_{zy} \left(\dot{\theta}_{rzy} + ps_{zy} - pf_{rzy} \right) + (ESVA_{zy} - 1)ao_{zy} \quad (A.1)$$

$$qf_{rzy} = qo_{zy} - ao_{zy} - af_{rzy} + ESVA_{zy}(ao_{zy} + af_{rzy} + ps_{zy} - pf_{rzy}) \quad (A.2)$$

Within this framework, Equations (1) and (2) describe the composite demand for intermediate inputs and the value-added–energy bundle. The variables ' qf_{rzy} ', ' pf_{rzy} ', ' qo_{zy} ', and ' ps_{zy} ' represent, respectively, the demand for inputs, input prices, final output quantity, and the supply price of the commodity in sector z and region y . ' $\dot{\theta}_{rzy}$ ' represents the input-biased technological change for input r in sector z and region y . ' ao_{zy} ' represents total factor productivity (TFP) changes, i.e., a Hicks-neutral technological change that affects all inputs uniformly. ' $ESVA_{zy}$ ' the elasticity of substitution, describes the relationship between intermediate inputs and the value-added–energy composite.

In the second tier of the production structure, the demand for primary inputs and the capital–energy bundle is determined according to Equations (3) and (4). Within the GTAP-E-POWER framework, energy inputs are positioned in the value-added nest, allowing substitution between capital and energy.

A.2.Value added–energy nest

$$qf_{rzy} = qf^{\text{"vaenl"zy}} - af_{rzy} + ESVAN_{zy} (\dot{\theta}_{rzy} + pf^{\text{"vaenl"zy}} - pf_{rzy}) \quad (\text{A.3})$$

$$qf_{rzy} = qf^{\text{"vaenl"zy}} + ESVAN_{zy} (pf^{\text{"vaenl"zy}} + af_{rzy} - pf_{rzy}) \quad (\text{A.4})$$

$$pf^{\text{"vaenl"zy}} = \sum_{r=VAEN} SHVAEN_{rzy} \times [pf_{rzy} - af_{rzy}] \quad (\text{A.5})$$

$$ps_{zy} = -a_{ozy} + \sum_{r=OUT-COMM} SHTC_{rzy} \times [pf_{rzy} - af_{rzy}] \quad (\text{A.6})$$

As shown in Equation (5), $pf^{\text{"vaenl"zy}}$ denotes the composite price of the value-added-energy bundle, calculated as a weighted mean of the prices of primary inputs (excluding capital) and the capital-energy composite. $SHVAEN_{rzy}$: denotes the share of each input's expenditure within this layer. $qf^{\text{"vaenl"zy}}$: denotes the demand for the value added-energy composite. Equation (A.6) denotes the percentage change index of the output supply price, calculated as the weighted mean of the prices of all inputs, including intermediate inputs and the composite of primary inputs and energy. $.SHTC_{rzy}$: denotes the share of input r 's cost within the total production expenditure of output z across region y . Based on Equation (A.6), enhancements in input efficiency and total factor productivity (TFP) result in lower output supply prices. $ESVAN_{zy}$: represents the elasticity of substitution between primary inputs and the capital-energy composite.

A.3. Intermediate inputs nest

$$qfd_{rzy} = qft_{rzy} + EARM_{zy} (pft_{rzy} - pf_{rzy}) \quad (\text{A.7})$$

$$qfm_{rzy} = qft_{rzy} + EARM_{zy} (pft_{rzy} - pfm_{rzy}) \quad (\text{A.8})$$

$$pft_{rzy} = SHRM_{rzy} \times pfm_{rzy} + (1 - SHRM_{rzy}) \times pfd_{rzy} \quad (\text{A.9})$$

The composite price of intermediate inputs (pft_{rzy}) is calculated as a weighted mean of the prices of domestic (pfd_{rzy}) and foreign (pfm_{rzy}) intermediate inputs. $SHRM_{rzy}$: denotes the share of the cost of imported input r in sector z within region y . $EARM_{zy}$: denotes the elasticity of substitution between domestic and imported goods (Armington elasticity).

A.4. Capital-energy nest

$$qf_{rzy} = qf^{\text{"cen"zy}} - af_{rzy} + ESCEN_{zy} (pf^{\text{"cen"zy}} + af_{rzy} - pf_{rzy}) \quad (\text{A.10})$$

$$pf^{\text{"cen"zy}} = \sum_{r \in CEN} SHCEN_{rzy} \times (pf_{rzy} - af_{rzy}) \quad (\text{A.11})$$

Within the capital-energy composite nest, the optimal demand for the capital-energy bundle is derived based on relative prices and factor-biased technological change.

$pf^{\text{"cen"zy}}$: Composite price of capital-energy in sector z , region y , $qf^{\text{"cen"zy}}$: composite quantity of capital-energy in sector z , region y . According to Equation (A.11), an increase in energy efficiency, $af^{\text{"eng"zy}}$, leads to a reduction in the price of the energy bundle. As a result of this price reduction, energy demand rises via the substitution effect. Conversely, based on Equations (A.10) and (A.12), these changes have a direct effect on energy demand. $ESCEN_{zy}$: denotes the elasticity

of substitution between capital and energy. $SHCEN_{rzy}$: denotes the share of the cost of each input within the corresponding production nest.

A.5. Energy nest

$$qf_{rzy} = qf^{\text{eng}"}_{zy} - af_{rzy} + ESELN_{zy}(pf^{\text{eng}"}_{zy} + af_{rzy} - pf_{rzy}) \quad (\text{A.12})$$

$$pf^{\text{eng}"}_{zy} = \sum_{r \in ENY} SHENY_{rzy} \times (pf_{rzy} - af_{rzy}) \quad (\text{A.13})$$

The composite demand for electricity and non-electricity is calculated using Equation (A.12).

Furthermore, the composite energy price $pf^{\text{eng}"}_{zy}$ is calculated based on Equation (A.13). $SHENY_{rzy}$: denotes the share of electricity and non-electric energy costs in sector z, region y. $ESELN_{zy}$: denotes the elasticity of substitution between electricity and non-electric energy.

A.6. Non-electricity nest

$$qf_{rzy} = qf^{\text{nelc}"}_{zy} - af_{rzy} + ESNEN_{zy}(pf^{\text{nelc}"}_{zy} + af_{rzy} - pf_{rzy}) \quad (\text{A.14})$$

$$pf^{\text{nelc}"}_{zy} = \sum_{r \in NELC} SHNELY_{rzy} \times (pf_{rzy} - af_{rzy}) \quad (\text{A.15})$$

Within the non-electric energy nest, the optimal demand for the coal–non-coal composite is derived, depending on relative energy prices as specified in Equation (14). The composite non-electric energy price ($pf^{\text{nelc}"}_{zy}$) is calculated as the weighted average of coal and non-coal energy prices. $SHNELY_{rzy}$: denotes the share of each energy input's cost within this layer. $ESNEN_{zy}$: substitution elasticity between coal and other non-coal energy sources.

A.7. Non-coal nest

$$qf_{rzy} = qf^{\text{ncn}"}_{zy} - af_{rzy} + ESNCN_{zy}(pf^{\text{ncn}"}_{zy} + af_{rzy} - pf_{rzy}) \quad (\text{A.16})$$

$$pf^{\text{ncn}"}_{zy} = \sum_{r \in NCN} SHNCOAL_{rzy} \times (pf_{rzy} - af_{rzy}) \quad (\text{A.17})$$

In this model, the non-coal energy inputs consist of oil, gas, and petroleum products. Equation (A.16) denotes the optimal demand for these energy inputs. The price of this input bundle is calculated based on Equation (A.17). $SHNCOAL_{rzy}$: denotes the cost share of non-coal energy carriers. $ESNCN_{zy}$: denotes the elasticity of substitution among non-coal energy carriers.

A.8. Base load-peak load nest

$$qf_{rzy} = qf^{\text{blpn}"}_{zy} - af_{rzy} + ESBPN_{zy}(pf^{\text{blpn}"}_{zy} + af_{rzy} - pf_{rzy}) \quad (\text{A.18})$$

$$pf^{\text{blpn}"}_{zy} = \sum_{r \in BLPN} SHBPN_{rzy} \times (pf_{rzy} - af_{rzy}) \quad (\text{A.19})$$

The result of the cost-minimization process is expressed as the demand function in Equation (A.18). Substitution between base-load and peak-load energy is represented by a CES-type function, with elasticity parameter $ESBPN_{zy}$. The composite electricity price index for base and peak load, $pf^{\text{blpn}"}_{zy}$, is calculated according to Equation (A.19). $SHBPN_{rzy}$: The cost share of each of

these two types of electricity in final consumption. $ESBPN_{zy}$: denotes the elasticity of substitution between base-load and peak-load electricity.

A.9. Peak load nest

$$qf_{rzy} = qf_{\text{pln}zy} - af_{rzy} + ESPKN_{zy}(pf_{\text{pln}zy} + af_{rzy} - pf_{rzy}) \quad (\text{A.20})$$

$$pf_{\text{pln}zy} = \sum_{r \in PLN} SHPKL_{rzy} \times (pf_{rzy} - af_{rzy}) \quad (\text{A.21})$$

The composite price index of energy carriers used for electricity generation during peak hours in sector z and region y , $pf_{\text{peak}zy}$, is calculated based on Equation (A.21). $SHPKL_{rzy}$: The cost share of each energy carrier in the peak-load electricity mix. $ESPK_{zy}$: Elasticity of substitution among energy carriers used for peak-load electricity generation.

A.10. Base load nest

$$qf_{rzy} = qf_{\text{bln}zy} - af_{rzy} + ESBAN_{zy}(pf_{\text{bln}zy} + af_{rzy} - pf_{rzy}) \quad (\text{A.22})$$

$$pf_{\text{bln}zy} = \sum_{r \in BLN} SHBSL_{rzy} \times (pf_{rzy} - af_{rzy}) \quad (\text{A.23})$$

In the final technology layer, the demand for base-load electricity is determined using a Constant Elasticity of Substitution (CES) function, with substitution elasticity $ESBAN_{zy}$, as specified in Equation (A.22). $pf_{\text{bln}zy}$: Composite price index of energy carriers used in base-load electricity generation. $SHBSL_{rzy}$: denotes the cost share of each energy input within this nest. $ESBAS_{zy}$: indicates the elasticity of substitution among energy carriers in the base-load nest.

In the standard version of the model, all technology coefficients (such as ao and pf) are treated as exogenous, while prices and quantities are determined endogenously.