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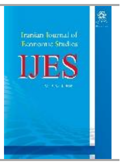

The effects of Energy Efficiency Improvements in the Electricity Sector on the Iranian economy: A Computable General Equilibrium Approach

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Abstract

Improving energy efficiency is one of the most important energy policies in many countries. This study mainly focused on the economic and environmental effects of energy efficiency improvements in Iran's electricity sector on Iran's economy using a computable general equilibrium framework. Furthermore, the potential benefits of carbon reduction were explored. The results showed that the most significant change occurred in the sectoral output. Other macroeconomic variables, such as GDP and export, also showed higher levels. Accordingly, it can be asserted that a combination of energy policies, such as carbon pricing and revenue recycling, that are aimed at improving energy efficiency can potentially have positive effects on both the economy and the environment. Therefore, energy efficiency improvements can be considered a cost-effective alternative to promoting sustainable development.

Highlights

- This study investigates the economic and environmental effects of energy efficiency improvements in Iran's electricity sector.
- The standard CGE model is extended by some modifications to consider environmental perspective.
- The combination of energy efficiency and environmental policies, have positive effects on both the economy and the environment.

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1. Introduction

Energy efficiency improvement is identified as one of the most important energy policies in many countries to reduce energy demands and carbon emissions. It is also regarded as a cost-effective and efficient way to reduce greenhouse gas (GHG) emissions (IEA, 2015; UNEP 2014). In recent years, there has been growing concern about the rapidly increasing greenhouse gases emissions and their potential impact on environmental changes, such as climate change.

Within the energy sector, CO_2 emissions from fuel combustion represent more than 75% of the anthropogenic GHG emissions in developed countries and about 60% of global emissions (IEA, 2019). Each year, large amounts of energy are lost during the production, transmission, distribution, and consumption of electricity, which highlights the importance of energy efficiency more than ever (Turner, 2009).

Iran is one of the largest owners of oil resources in the world. Due to the abundance of energy resources and low prices of fossil fuels in Iran, energy efficiency and carbon emissions reduction have been largely ignored by policymakers.

It is possible to develop a low-carbon economy through energy efficiency improvement, demand-side management, and renewable energy development. Furthermore, some mechanisms, such as sustainable and clean development mechanisms (SDM and CDM, respectively), can be used to curb energy use. These mechanisms are market-based and are used as environmental policy tools to tackle rising greenhouse gases by reducing carbon emissions. The energy efficiency improvement, which may result in a rebound effect, can be complemented with appropriate carbon/energy pricing, either through taxation or emission trading schemes (Turner & Hanley, 2011).

Two-thirds of global CO_2 emissions in 2013 originated from just ten countries (IEA, 2019). Iran is among the top 10 CO_2 emitting countries and needs to reduce its consumption of fossil fuels and GHG emissions by setting energy and climate policy goals. Electricity generation in Iran is still highly dependent on traditional technologies based on fossil fuels. This is reflected in its high energy and carbon intensities, which are above the global average (Iran Energy Balance Sheet, 2016). These data reveal relatively low energy productivity in Iran, highlighting the importance of assessing the impacts of energy-climate policies on both the energy system and the economy.

Another important point concerning Iran's overall climate change policy is that in the 2015 United Nations Climate Change Conference in Paris, Iran made a commitment to reduce its CO_2 emissions by 2030 by 8-12% compared to the 2005 level. In its long-term development plan for the energy sector, Iran has set a target to increase power plant efficiency by 20%. These national development strategies can improve energy efficiency.

In this regard, some studies have used Computable General Equilibrium (CGE) models to investigate energy efficiency improvement for the entire Iranian economy. Most previous studies have focused on the efficiency and the rebound effect of aggregate energy consumption. This study aimed to investigate the effects of energy efficiency improvements in the electricity sector by focusing on economic and environmental factors. Furthermore, some market-based incentives designed to accelerate technology development and deployment in Iran were considered in this study.

This article is divided into five sections. In the next section, the theoretical and methodological framework of the study model is presented. The data used in the model and scenario definitions are discussed in Section 3. In Section 4, the simulation results are presented and analyzed. Finally, Section 5 provides some concluding remarks.

2. Literature Review

By improving energy efficiency, the same amount of output can be produced using less energy; therefore, it reduces energy demand. In more advanced stages of industrialization, energy efficiency reflects the adoption of more efficient technologies for energy production combined with structural changes in the economy (Stern, 2003).

In developing countries, energy use per unit of GDP is very high (IEA, 2019) and the importance of energy efficiency improvements can hardly be overestimated. There is an extensive debate in the energy economics literature on the real impact of improving energy efficiency. In recent years, energy efficiency policies have been widely used in some European countries. The effectiveness of these policies has been challenged by the “rebound effect” (Turner, 2013). Some researchers have argued that energy efficiency policies will lead to rebound, or backfire, effects (Khazzoom, 1980; Brookes, 1990; Herring, 1999; Saunders, 2000; Hanley et al., 2006). The backfire effect occurs when the expected beneficial impacts of energy efficiency are partially offset as a result of the increase in demand in response to the fall in the effective price of energy services. There is a general agreement among economists that a certain degree of rebound is expected following improvements in energy efficiency (Barker et al., 2009; Gillingham et al., 2013).

If energy prices are considered constant, whether an improvement in energy efficiency can reduce energy use or not depends on the general equilibrium own-price elasticity of demand for energy. Where energy efficiency improvement is greater than unity, the fall in the implicit price of energy will generate an increase in expenditure on energy, leading to a rise in the overall energy use (Hanley et al., 2009). However, the presence of a strong rebound suggests that adopting such policies alone is insufficient to help a country achieve environmental improvements.

Since direct fuel combustion and indirect GHG emissions are associated with intermediate goods, electricity is among the top GHG-intensive sectors. Some energy alternatives, such as renewable energies, have received increasing consideration in recent years. Although renewable energies have already attracted great attention in developed countries, there is little prospect of them being widely adopted in developing countries due to the high generation costs of renewable energies and other economic reasons. Hence, in developing countries and elsewhere, improving energy efficiency is considered as a powerful and cost-effective method to promote low-carbon development and thus achieve more economic growth, more sustainable development, and a cleaner environment (World Bank, 2009).

The energy efficiency policies may not, in themselves, be sufficient to secure environmental improvements. For these policies to result in significant environmental improvements, they must be complemented with some other policy initiatives, such as SDM and CDM, which are designed to moderate incentives to increased energy consumption. The CDM assumes that developing countries have no mandatory obligation to reduce GHG emissions; thus, it issues salable certified emission reduction (CER) credits to committed countries as to encourage them to reduce their GHG emissions. The CDM allows the exchange of CERs between all countries, including developed and developing countries.

Numerous studies have focused on the importance of energy efficiency. The following literature review summarizes the results of previous studies on energy efficiency, low-carbon strategies, and related environmental issues.

Some studies have reviewed and applied the CGE model as a tool to analyze energy and environmental policies (Bergman, 1991; Bergman & Henrekson, 2005; Aydın, 2018). There have been several studies on the economy-wide effects of energy efficiency improvements (Lu & Lu, 2018; Bohringer & Rivers, 2018; Bataille & Melton, 2017; Pardo Martínez, 2010; Turner, 2009; Barker et al., 2007).

Some other studies have focused on clean development and low-carbon strategies. By applying CGE models, some of these studies investigated the effects of CDM at the global level (Nijkamp et al., 2005; Anger et al., 2007) or at the country level (Montaud & Pécastaing, 2015; Montaud & Pécastaing, 2016) while other studies examined the macroeconomic impact of CDM implementation. The numerical simulation of macroeconomic shocks generated by current and future CDM projects revealed the significant potential impact of such projects on employment and economic growth (Montaud & Pécastaing, 2016). As regards environmental incentives, the rebound effects of energy efficiency may be limited (Mahmood & Marpaung, 2014).

Several studies have been conducted on clean development strategies, such as energy efficiency, energy replacement, and green tax, in Iran (Soltanieh et al., 2009; Sekhavatjou et al., 2011; Ashena et al., 2016; Mirhosseini et al., 2017). Table 1 summarizes the previous related studies.

CGE models have been used to estimate the economy-wide effects of an improvement in energy efficiency (Guerra & Sancho, 2010; Wei, 2010). Some studies have evaluated the impacts of an exogenous and costless energy efficiency improvement (Manzour et al., 2011), or the rebound effects of energy efficiency improvement (Khoshkalam, 2015; Salimian et al., 2017; Salimian et al., 2019;

Faridzad et al., 2019), on the Iranian economy using a CGE model. However, few studies have simultaneously investigated the improvements in energy efficiency and environmental-friendly policies on the economy. Thus, this study aimed to examine the impacts of energy efficiency improvements, along with carbon pricing, on the Iranian economy.

Table 1. A summary of previous studies

<table>
<tr><th>Authors</th><th>Findings</th><th>Methodology</th></tr>
<tr><td>Allan et al. (2007)</td><td>Between 2000 and 2020, the improvement of energy efficiency in the energy production sector was 5% in the United Kingdom.
<table>
<tr><th></th><th>Short-run findings</th><th>Long-run findings</th></tr>
<tr><td>GDP</td><td>+0.11%</td><td>+0.17%</td></tr>
<tr><td>Consumption</td><td>+0.06%</td><td>+0.14%</td></tr>
<tr><td>Investment</td><td>-0.03%</td><td>+0.21%</td></tr>
<tr><td>Export</td><td>-0.23%</td><td>+0.21%</td></tr>
<tr><td>Import</td><td>-0.27%</td><td>+0.23%</td></tr>
<tr><td>Employment</td><td>+0.2%</td><td>+0.21%</td></tr>
</table></td><td>Top-down</td></tr>
<tr><td>Barker et al. (2007)</td><td>In the United Kingdom, energy efficiency increased GDP by about 0.1% while decreasing prices by about 3% during 2000-2010,.</td><td>Top-down and bottom-up</td></tr>
<tr><td>Neves et al. (2008)</td><td>Energy efficiency can lead to better productivity, reliability, and process control. It can also decrease operation and maintenance costs.</td><td>Bottom-up</td></tr>
<tr><td>Vikström (2008)</td><td>During 1957-1962, the energy efficiency of all the sectors increased by 12-15% in Sweden. During the same period, the GDP increased by 0.5% and the average of the annual growth was 0.1%.</td><td>Top-down</td></tr>
<tr><td>Mills et al. (2008)</td><td>Productivity enhancement, process control, and reliability can be achieved by energy efficiency improvements. These improvements can also reduce operation and maintenance costs.</td><td>Bottom-up</td></tr>
<tr><td>Barker et al. (2009)</td><td>The global GDP may increase by up to 0.28% by the current and committed energy efficiency policies by 2030.</td><td>Top-down</td></tr>
<tr><td>Manzour et al. (2011)</td><td>The improvements in electricity efficiency can have 14.2% rebound effects. The differences between rebound effects across electricity-consuming sectors were significant.</td><td>A CGE model</td></tr>
<tr><td>Ryan & Campbell (2012)</td><td>The improvements in energy efficiency can enhance asset values, industrial productivity, health, working conditions, and quality.</td><td>Survey</td></tr>
<tr><td>Khoshkalam Khosroshahi (2015)</td><td>The effect of a 10% improvement in gasoline and diesel fuel efficiency showed a total rebound effect of about 13%, indicating that increased efficiency was offset by energy demand increase.</td><td>A CGE model</td></tr>
<tr><td>Ashena et al. (2016)</td><td>Economic growth and sustainable development were found to be the benefits of fuel switching in Iran. According to the findings, climate investment funds could lead to some benefits for the environment, such as lower emissions.</td><td>A CGE model</td></tr>
<tr><td>Mirhosseini et al. (2017)</td><td>Labor tax and capital tax on the environment will change GDP, welfare, and unemployment.</td><td>A CGE model</td></tr>
<tr><td>Bataille & Melton (2017)</td><td>The energy efficiency in Canada increased GDP (+2%), employment (+2.5%), and household welfare (+1.5%) between 2002 and.</td><td>Top-down</td></tr>
</table>

Table 1 (Continued). A summary of previous studies

Authors	Findings	Methodology
International Energy Agency (2018)	A negligible increase in demand for energy could double the size of the global economy by 2040.	Survey and partial equilibrium models
Antonietti & Fontini (2019)	Higher levels of oil prices will lead to a marginal increase in average energy efficiency. The important point is that this increase was significantly different among regions throughout the world.	Econometric (panel data)
Kim & Brown (2019)	In industrialized nations, some factors, such as governance strategies that improve energy performance standards, can stimulate energy innovation.	Econometric (panel data)
Hadian & Behzadi (2019)	Based on the results, the highest size of the rebound effect corresponding to the urban household's sector was observed when there was a 5% improvement in oil and natural gas energy efficiency.	A CGE model

3. Model

CGE models have been widely used to analyze the effects of various kinds of strategies and policies on economic parameters (Wu et al., 2019). These models enable the researchers to assess the direct, indirect, and even induced effects of a variety of economic policies (Lekavicius et al., 2019). The methodology used in this paper is illustrated in Figure 1.

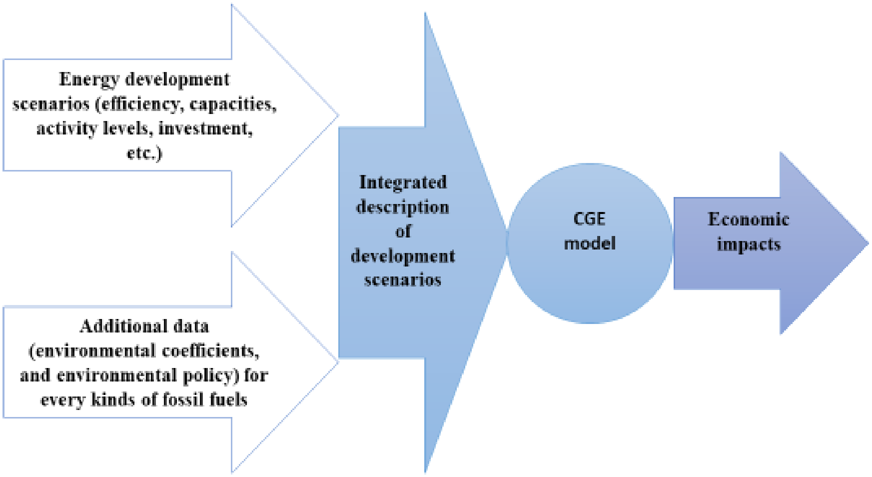

Figure 1. The effects of energy efficiency improvements in electricity sector scenarios.
***Source**: Authors' proposed framework based on the literature review.*

The CGE model considered in this paper included the production module, trade module, income and expenditure module, environment module, and model closure and market-clearing module. The production module was described using the nested constant elasticity of substitution (CES) production function, in which capital, labor, energy, and other non-energy intermediate inputs were considered as the production input while minimizing costs was regarded by the producers as the production principle.

In the trade module, the Armington assumption was applied to describe the relationship between domestic production and imports using a CES function. A constant elasticity transformation (CET) function was used to describe the substitution relationship between products for domestic use and export products.

In the model, institutions were represented by households, enterprises, government, and the rest of the world. The income and expenditure module mainly described the income and expenditure activities of households, enterprises, and the government. Primary incomes were distributed to different agents on the basis of their factor endowments and access to transfer and foreign incomes. The government has two sources of income: The lump-sum transfer from institutions and tax revenues. The households use their income for consumption, saving, paying direct taxes, and transfers to other institutions. Enterprise incomes are allocated to direct taxes, savings, and transfers to other institutions. The government uses income tax revenues for consumption expenditures and transfers to other institutions. The final institution is the rest of the world. Transfer payments between the rest of the world and domestic institutions and factors are all fixed in foreign currency.

In this article, the environment module represents the effects of changes in energy consumption following the changes in carbon emission intensity.

Macroeconomic closure is mandatory for solving a model mathematically and achieving equilibrium (Lofgren et al., 2002). In the market-clearing module, four closure rules were considered as follows: (i) Market balance of primary inputs: In the labor market, due to the assumption of incomplete employment and perfect mobility, the changes in employment in each sector at the level of fixed wages balance the market. In the capital market, it is assumed that the supply of capital is fixed within a given time period and cannot move across activities; (ii) saving-investment closure: For saving-investment closure, the real investment is determined based on the total available savings; (iii) external closure: It assumes that foreign savings, or current account deficit, is exogenous whereas the exchange rate is endogenous; (iv) general government closure: The budget deficit is assumed to be exogenous while treating government consumption is considered to be endogenous.

The CGE model of this study was established on the basis of a standard model (Lofgren et al., 2002). Based on the objectives of this study, the production block equations are described below. Other equations and constraints were established based on a standard CGE model and are presented in the appendix.

3.1 Production

The production function shows the process of converting inputs into outputs. Inputs are categorized into three types: Intermediate commodities, energy commodities, and primary factors (capital and labor). Production was modeled using the nested CES function, which related production factors based on the elasticity of substitution (Figure 2). The nested production structure of this study was established based on what were suggested in Lofgren et al. (2002), Khoshkalam (2015), Salimian et al. (2017), Salimian et al. (2019) and Manzour and Haghighi (2012).

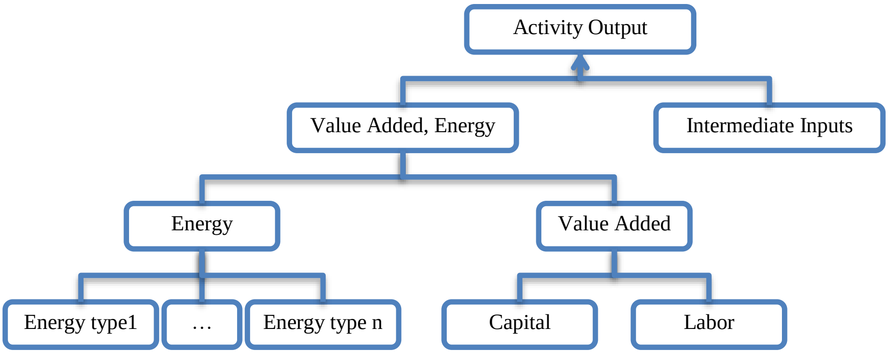

Figure 2. The nested production structure

The production structure is characterized by capital, labor, energy, and materials combined in a nested CES function. As shown in Figure 2, the combination of labor and capital produces value-added, which together with energy produces value-added and energy. In turn, intermediate inputs, on the one hand, and value-added and energy, on the other hand, combine to generate total output in each sector (Khoshkalam, 2015; Manzour & Haghighi, 2012).

At the top level, the total production is obtained by combining intermediate goods and value-added and energy composite (Manzour & Haghighi, 2012). Thus, the production function represents the final output ($\mathrm{QA_a}$) in sector a:

$$QVAE_a = iva_a.QA_a \tag{1}$$

$$QINT_{ca} = ica_{ca}.QA_a \tag{2}$$

Where $\mathrm{iva_a}$, is the unit input coefficient for value-added and energy composite ($\mathrm{QVAE_a}$), and $\mathrm{ica_{ca}}$ is the unit input coefficient for aggregate intermediates (non-tradable and tradable commodities). The total production value of each sector can be estimated by the following equation:

$$PQA_a.QA_a = QVAE_a.PVAE_a + PQINT_a.QINT_a \tag{3}$$

In the subsequent nesting levels, the CES function is used to describe the substitution relationships. A sector uses intermediate inputs of the composite commodity in a fixed proportion with a composite primary factor input (Lofgren et al., 2002).

At the second level, the demands for aggregate intermediate inputs were defined as Leontief functions of the activity level:

$$QINT_{ca} = ica_{ca}.QINTA_a \tag{4}$$

Value-added and energy composite ($QVAE_a$) is a CES function of the quantities of value-added (QVA_a) and total energy inputs (QVE_a):

$$QVAE_a = a_a^{vae}(\delta_a^{vae}.QVA_a^{-\rho^{vae}} + (1-\delta_a^{vae}).QVE_a^{-\rho^{vae}})^{\frac{1}{-\rho^{vae}}} \tag{5}$$

Where a_a and δ_a are the technology and share parameters of the CES function, respectively. The total value of $QVAE_a$ was calculated based on the following equation:

$$PVAE_a.QVAE_a = QVA_a.PVA_a + PVE_a.QVE_a \tag{6}$$

The optimal mix of total energy inputs and value-added is a function of the relative prices of value-added and the aggregate energy input (PVE_a, PVA_a):

$$\frac{QVA_a}{QVE_a} = (\frac{PVE_a a}{PVA_a}.\frac{\delta_a^{vae}}{1-\delta_a^{vae}})^{\frac{1}{1+\rho^{vae}}} \tag{7}$$

At the last level, value-added and total energy input functions are presented. The primary factors composite is a CES aggregation of labor and capital with a Cobb-Douglas form:

$$QVA_a = ad_a.\prod_f QF_{fa}^{\alpha_{fa}} \tag{8}$$

The quantity demanded for each primary factor (QF_{fa}) is the point at which the marginal cost of each factor is equal to the marginal revenue. Here, WF_f is the average price of factor, $WDIST_{fa}$ is the wage distortion factor for factor f, and PVA_a is the value-added price:

$$WF_f.WDIST_{fa}.QF_{fa} = QVA_a.PVA_a.\alpha_{fa} \tag{9}$$

Also, the total energy input is the combination of demands for fossil fuels ($QFE_{ec,a}$):

$$QVE_a = a_a^{ve}(\sum_{ec}\delta_a^{ve}.QFE_{ec,a}^{-\rho^{ve}})^{\frac{-1}{\rho^{ve}}} \tag{10}$$

Where ad_a is the technology parameter in the CES value-added function and α_{fa} is the production factor share parameter.

By maximizing the profit function, the demand for fossil fuels can be obtained based on the total energy input function. The total value of energy input was calculated based on Equation 12.

$$QFE_{ec,a} = QVE_a(\frac{PDE_a}{PVE_a}.\frac{a_a^{ve\rho^{ve}}}{\delta_a^{ve}})^{\frac{-1}{1+\rho^{ve}}} \tag{11}$$

$$PVE_a.QVE_a = \sum_{ec} PDE_{ec,a}.QFE_{ec,a} \tag{12}$$

We defined an increase in energy efficiency as a technological improvement that could increase the energy services generated by each unit of physical energy. It was assumed that the energy efficiency improvement parameter (γ_a) would decrease the demands for fossil fuels in the electricity sector. Therefore, the fossil fuels demand variable could be adjusted by γ_a:

$$QVE_a = a_a^{ve}(\sum_{ec}\delta_a^{ve}\frac{QFE_{ec,a}^{-\rho^{ve}}}{\gamma_a})^{\frac{-1}{\rho^{ve}}} \tag{13}$$

$$QFE_{ec,a} = QVE_a(\frac{PDE_a}{PVE_a}.\frac{a_a^{ve\rho^{ve}}}{\delta_a^{ve}}.\frac{1}{\gamma_a{}^{\rho^{ve}}})^{\frac{-1}{1+\rho^{ve}}} \tag{14}$$

3.2 Energy Consumption and GHG Emissions

The energy efficiency improvement in the policy scenarios was modeled as being exogenous and costless (Grepperud & Rasmussen, 2004; Anson & Turner, 2009; Turner & Hanley, 2011). In other words, it was assumed that efficiency improvement was not necessarily due to the application of specific policies; therefore, the costs and financing relationships were not considered in the model (Manzour et al., 2011). Furthermore, in this study, the rebound effect of energy efficiency improvements was ignored because it was assumed that the environmental benefits of the policies and carbon pricing could potentially neutralize the rebound effect.

Given that the cost of increasing efficiency is zero, this analysis only shows the benefits of improving efficiency and its distribution in the economy. The study of McKinsey and Company (2009) on marginal abatement costs of carbon emissions shows negative costs for some efficiency improvements (Ackerman & Baono, 2011).

In line with the objectives of this study, the standard CGE model was also extended by two modifications, including an environmental perspective and the relative foreign revenues (CER price). CO_2 emissions were linked in fixed proportions to fossil fuel consumption, namely, emission coefficients. The carbon emission for each sector was calculated based on the product of fossil fuel consumption and the CO_2 emission coefficient (Equation 15). The CO_2 emission coefficient was differentiated by the specific carbon content of fuels (IPCC, 1995).

Different sectors of the economy consume energy and consequently emit pollutant gases, but, based on the objectives of this study, we just considered the pollution emissions from the production sectors.

$$EM_a = \sum_{ec} QFE_{eca}.ef_{ec}.\frac{1}{CF_{eca}} \tag{15}$$

$$CDMR = PCER(\sum_a EM0_a - \sum_a EM_a) \tag{16}$$

Where EM_a is the emissions for each sector, ef_{ec} is the emissions coefficients for each fossil fuel, CF_{eca} is the energy conversion coefficient, and PCER is the CER price.

Equation (16) shows the monetary value of carbon emission reduction, which was calculated using the baseline. The validation of the model used in this study was carried out and the results are presented in the appendix.

4. Data and Simulation Results

4.1 Data

In this study, an integrated database of energy use and economic activity were used. The year 2006 was selected as the baseline year because, at the time of this study, the latest comprehensive energy input-output table for Iran was only available for this year (Ministry of Energy, 2006). Intermediate and final demand values are provided for Iran’s economy at a disaggregation of 10 sectors based on the objectives of this study and the last energy input-output table for Iran. The fossil fuels considered in this study included petrol, kerosene, gasoline, fuel oil, liquid gas, natural gas.

To calculate carbon emissions, the energy price in the base year was determined by converting energy consumption into physical terms. Then, carbon emissions were calculated using the emission coefficients provided by IPCC (1995). There is currently no single price for CER. The price of carbon has varied over the years and ranged from $ 0.1 to $ 25.

The Social Accounting Matrix (SAM) constitutes the core dataset of the model used in this study. Most of the model parameters were set endogenously based on the SAM. However, other parameter values were also required to inform the model. Share parameters and elasticity parameters were two kinds of parameters that had to be identified exogenously. Share parameters were obtained from SAM while elasticity parameters were extracted from previous studies (Salimian et al., 2019; Khoshkalam, 2017; Manzour et al., 2011; Khiabani, 2008). The study considered the elasticity of substitution between domestic supply and export as σ_c=2.5, the elasticity of transformation between domestic supply and export as σ_t=2, the elasticity of substitution between labor and capital as $\sigma_{va} = 0.5$ (Khiabani, 2008), the elasticity of substitution between energy and value-added as $\sigma_{vae} = 0.5$ (Manzour et al., 2011), and the elasticity of substitution between energy carriers as $\sigma_{ve} = 0.5$ (Khoshkalam, 2017; Salimian et al., 2019).

4.2 Simulation Results

The prospects of the Ministry of Energy and the electricity operational program reports of the Ministry were considered to determine the scenarios of this study. In a report by the electricity industry, it was estimated that the efficiency of thermal power plants would increase from 37% to 42% by 2020 (Ministry of Energy, 2015). Furthermore, in the long-term development plan of Iran for the energy sector, it is predicted that the efficiency of thermal power plants will increase by about 12% (Ministry of Energy, 2014).

Scenarios SC1, SC2, and SC3 corresponded to 5, 10, and 15% increase in energy efficiency, respectively. The efficiency shock was applied to causes a change in production technology. It was assumed that the efficiency could occur at no cost and that the resulting rebound effect of this assumption may be minimized by the beneficial effects of environmental mechanisms[1]. As such, the results only reflected the gains derived from the improvements in energy efficiency as well as the distribution of the overall gains to the economy.

The scenarios were simulated in three cases based on different carbon prices. A range of carbon prices, varying between 0 and 10 dollars, was considered. Zero price elasticity was regarded as the condition in which environmental mechanisms

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[1] Some studies have shown negative or zero technical potential for energy savings in their bottom-up analysis (McKinsey & Company, 2009; Ackerman & Bueno, 2011).

were not established and no price was set for carbon. This condition can be used to examine whether the international commitments on carbon emission reductions have been fulfilled.

Tables 2, 3, and 4 report the impacts of different CER prices (PCER) on the macroeconomic variables in all the three simulated scenarios. The simulation results showed that energy efficiency improvements in the electricity sector had a positive impact on GDP. Higher PCERs had a stronger positive effect on GDP. It was assumed that Iran had no mandatory obligation to reduce GHG emissions and may sell the resulted CER credits to other countries.

Table 2. The macroeconomic impacts of energy efficiency if PCER=0

Macroeconomic variables (% change)	SC1	SC2	SC3
Gross domestic products	0.002	0.004	0.006
Fossil fuel demand in the electricity sector	-3.633	-6.963	-10.026
Oil product export	0.010	0.019	0.028
Natural gas export	0.001	0.002	0.004
Total carbon emission	-0.531	-1.018	-1.466

Source*: Authors' estimation.*

Table 3. The macroeconomic impacts of energy efficiency if PCER=1

Macroeconomic variables (% change)	SC1	SC2	SC3
Gross domestic products	0.06	0.011	0.015
Fossil fuel demand in the electricity sector	-2.816	-5.43	-7.878
Oil product export	0.488	0.99	1.515
Natural gas export	0.083	0.173	0.237
Total carbon emission	-0.345	-0.665	-0.963
Carbon revenues (in billion Rials)	179.69	346.9	502.91

Source*: Authors' estimation.*

Table 4. The macroeconomic impacts of energy efficiency if PCER=10

Macroeconomic variables (% change)	SC1	SC2	SC3
Gross domestic products	0.13	0.12	0.02
Fossil fuel demand in the electricity sector	-0.92	-1.779	-2.548
Oil product export	1.809	4.83	11.025
Natural gas export	0.278	0.569	0.921
Total carbon emission	0.087	0.193	0.370
Carbon revenues (in billion Rials)	587.15	1138.25	1639.73

Source*: Authors' estimation.*

Energy consumption by the electricity sector decreased more in scenarios with higher energy efficiency. For example, the demand for fossil fuels dropped from -3.63% in SC1 to -10.02% in SC3 when PCER was assumed to be 0 (Table 2). However, in higher PCERs, the decrease in the energy demand was less marked because carbon revenues were recycled into the economy and increased carbon emission (Table 4).

The export of oil products and natural gas increased in all scenarios and price classes. The natural gas export increased less than did the oil products export due to the limitations that hinder the transportation of natural gas. The increase in the export of oil products varied from 0.01% to % 0.02 in the first price class and from 1.8% to 11.02% in the last price class.

Some of the macroeconomic effects of the energy efficiency improvements in the electricity sector were relatively small. This can be explained by the fact that the model was applied in the short run. While the capital stocks are fixed in the short run, they are optimally adjusted in the long run.

The resulting emission reductions in the electricity sector and the total pollutants could be attributed to the reductions in energy demand. The simulations revealed that emission reductions could have a positive economic and environmental effect. The revenues estimated to be raised from carbon reduction in the electricity sector ranged between 180 and 500 billion Rials in the second PCER and between 587 1640 billion Rials in the third PCER.

Tables 5-7 show carbon emission changes based on various types of fossil fuels in different simulated scenarios and PCERs. Fuel oil and natural gas showed more negative changes. However, in higher PCERs, the rate of emissions from natural gas was estimated to increase due to an increase in carbon revenues, which are expected to bring about new investments and increase production.

Table 5. Carbon emission changes based on different types of fossil fuels if PCER=0

Types of fossil fuels (% change)	SC1	SC2	SC3
Petrol	0.014	0.027	0.039
Kerosene	0.034	0.066	0.095
Gasoline	-0.134	-0.256	-0.369
Fuel oil	-2.243	-6.215	-8.949
Liquid gas	0.074	0.089	0.129
Natural Gas	-0.718	-1.376	-1.981

***Source**: Authors' estimation.*

Table 6. Carbon emission changes based on different types of fossil fuels if PCER=1

Types of fossil fuels (% change)	SC1	SC2	SC3
Petrol	0.137	0.261	0.372
Kerosene	-0.03	-0.06	-0.09
Gasoline	-0.009	-0.025	-0.039
Fuel oil	-2.508	-4.841	-7.019
Liquid gas	0.37	0.76	1.176
Natural Gas	-0.416	-0.797	-1.143

***Source**: Authors' estimation.*

Table 7. Carbon emission changes based on different types of fossil fuels if PCER=10

Types of fossil fuels (% change)	SC1	SC2	SC3
Petrol	0.398	0.659	0.529
Kerosene	-0.187	-0.444	-0.957
Gasoline	0.253	0.359	0.020
Fuel oil	-0.812	-1.598	-2.413
Liquid gas	1.324	3.864	10.478
Natural Gas	0.308	0.777	1.793

***Source**: Authors' estimation.*

A change in the output of one sector affects the output of other sectors. The next three tables (Tables 8-10) present the changes in the sectoral output. In different PCER, the electricity output increased by 0.3% and 4.43% in the first and last scenarios, respectively. Based on the results, the improvements in energy efficiency had an overall positive impact on almost all sectors, but the impact was limited. Outputs increased mostly in those sectors that had greater energy intensity. Coal production and oil products production were found to have changed more in comparison with other sectors (Tables 8-10).

Table 8. The changes in the sectoral output following the improvements in energy efficiency if PCER=0

Sectors	SC1	SC2	SC3
Agriculture	0.000	0.000	0.000
Industry and mining	0.002	0.004	0.005
Transport	0.000	0.000	-0.001
Services	0.003	0.005	0.007
Construction	-0.004	-0.007	-0.010
Oil and gas extraction	0.000	0.000	0.000
Coal production	0.003	0.006	0.008
Oil products production	0.010	0.020	0.028
Gas production and distribution	0.001	0.003	0.004
Electricity production	0.328	0.634	0.921

***Source**: Authors' estimation.*

Table 9. The changes in the sectoral output following the improvements in energy efficiency if PCER=1

Sectors	SC1	SC2	SC3
Agriculture	0.000	0.000	-0.001
Industry and mining	-0.007	-0.015	-0.022
Transport	0.031	0.060	0.087
Services	0.019	0.036	0.053
Construction	-0.155	-0.301	-0.438
Oil and gas extraction	0.00	0.002	0.002
Coal production	4.745	8.903	12.585
Oil products production	0.487	0.987	1.511
Gas production and distribution	0.09	0.173	0.250
Electricity production	0.689	1.33	1.931

***Source**: Authors' estimation.*

Table 10. The changes in the sectoral output following the improvements in energy efficiency if PCER=10

Sectors	SC1	SC2	SC3
Agriculture	-0.002	-0.005	-0.009
Industry and mining	-0.030	-0.073	-0.163
Transport	0.102	0.192	0.254
Services	0.056	0.108	0.155
Construction	-0.505	-1.014	-1.610
Oil and gas extraction	0.003	0.005	0.006
Coal production	14.496	25.945	34.953
Oil products production	1.804	4.862	11.555
Gas production and distribution	0.288	0.546	0.737
Electricity production	1.516	2.976	4.432

***Source**: Authors' estimation.*

The impacts of energy efficiency improvements on employment were dependent on the choice of technology in production. Tables 11, 12, and 13 present the sectoral impacts of energy efficiency improvements on employment. The results showed a high reduction in employment in the electricity sector. However, the sectoral results were mixed; for instance, the employment increased in most sectors, except in the agriculture, industry, and construction sectors. Due to the closure rule and the fixed supply of primary factors, cross-sectoral factor mobility could not be ruled out, which may explain why employment increased in some sectors but decreased in some others.

There are a number of key parameters that are likely to govern the extent of the rebound. In other words, the simulation results may be sensitive to the elasticity of substitutions in a CGE model (Hanely et al., 2009). Hence, an effective sensitivity analysis of these elasticities should be conducted to confirm that the elasticities change directly with the length of the time interval of the analysis.

Table 11. Sectoral employment following the improvements in energy efficiency if PCER=0

Sectors	SC1	SC2	SC3
Agriculture	-0.002	-0.005	-0.007
Industry and mining	0.0083	0.0159	0.022
Transport	-0.005	-0.010	-0.015
Services	0.008	0.0160	0.0231
Construction	-0.008	-0.017	-0.024
Oil and gas extraction	-0.009	-0.018	-0.025
Coal production	0.006	0.011	0.016
Oil products production	0.057	0.109	0.158
Gas production and distribution	0.003	0.007	0.011
Electricity production	-0.603	-1.157	-1.668

***Source**: Authors' estimation.*

Table 12. Sectoral employment following the improvements in energy efficiency if PCER=1

Sectors	SC1	SC2	SC3
Agriculture	-0.009	-0.018	-0.026
Industry and mining	-0.034	-0.067	-0.100
Transport	0.167	0.322	0.467
Services	0.065	0.125	0.181
Construction	-0.366	-0.710	-1.034
Oil and gas extraction	0.081	0.154	0.221
Coal production	10.624	20.413	29.459
Oil products production	2.796	5.740	8.897
Gas production and distribution	0.455	0.879	1.275
Electricity production	0.573	1.110	1.617

Source*: Authors' estimation.*

Table 13. Sectoral employment following the improvements in energy efficiency if PCER=10

Sectors	SC1	SC2	SC3
Agriculture	-0.025	-0.054	-0.098
Industry and mining	-0.138	-0.335	-0.753
Transport	0.557	1.071	1.518
Services	0.193	0.372	0.541
Construction	-1.192	-2.381	-3.766
Oil and gas extraction	0.278	0.496	0.559
Coal production	34.295	65.293	92.162
Oil products production	10.692	30.995	86.411
Gas production and distribution	1.479	2.832	3.904
Electricity production	3.309	6.627	10.136

Source*: Authors' estimation.*

The elasticity of substitution between energy and value-added, σ_{vae}, and the elasticity of substitution between energy carriers, σ_{ve}, were the parameters that could affect the extent of the rebound. Therefore, as it can be observed in Tables 14 to 16, the values of σ_{ve} and σ_{vae} varied around their base case ($\sigma_{vae} = 0.5$ and $\sigma_{ve} = 0.5$). Here, the focus is only on the second scenario because it was observed that the two above-mentioned parameters showed different values only if PCER=1. During the sensitivity analysis, each of these two parameters was changed independently. Sensitivity analysis indicated that the simulation results were robust to the alternative elasticity of substitution.

Table 14. The effects of changing elasticities on the macroeconomic impacts of improvements in energy efficiency if PCER=1

	Sensitivity analysis					
	ρ_{vae}=0.4	ρ_{vae}=0.5	ρ_{vae} =0.6	ρ_{ve} =0.4	ρ_{ve}=0.5	ρ_{ve} =0.6
Changes in the macroeconomic impacts of improvements in energy efficiency if PCER=1						
GDP	0.011	0.01	0.011	0.013	0.01	0.009
Fossil fuel demand in the electricity sector	-4.83	-5.43	-5.968	-6.746	-5.43	-4.544
Oil product export	0.872	0.99	1.093	1.262	0.99	0.812
Natural gas export	0.156	0.173	0.188	0.214	0.173	0.145
Total carbon emission	-0.583	-0.665	-0.739	-0.826	-0.665	-0.557
Carbon revenues (in million dollars)	308.533	346.9	381.238	430.978	346.9	290.254

***Source**: Authors' estimation.*

Table 15. The effects of changing elasticities on the impacts of energy efficiency improvements on sectoral output if PCER=1

	Sensitivity analysis					
	ρ_{vae}=0.4	ρ_{vae}=0.5	ρ_{vae} =0.6	ρ_{ve} =0.4	ρ_{ve}=0.5	ρ_{ve} =0.6
Changes in the impacts of energy efficiency improvements on sectoral output if PCER=1						
Agriculture	-0.001	-0.001	-0.001	-0.002	-0.001	-0.001
Industry and mining	-0.012	-0.015	-0.017	-0.018	-0.015	-0.012
Transport	0.054	0.061	0.066	0.075	0.061	0.051
Services	0.033	0.036	0.039	0.045	0.036	0.03
Construction	-0.267	-0.301	-0.331	-0.375	-0.301	-0.251
Oil and gas extraction	0.001	0.002	0.002	0.002	0.002	0.001
Coal production	7.973	8.903	9.726	10.91	8.903	7.52
Oil products production	0.872	0.99	1.093	1.262	0.99	0.812
Gas production and distribution	0.156	0.173	0.188	0.214	0.173	0.145
Electricity production	1.284	1.33	1.373	1.654	1.33	1.113

***Source**: Authors' estimation.*

Table 16. The effects of changing elasticities on the impacts of energy efficiency improvements on sectoral employment if PCER=1

	Sensitivity analysis					
	σ_{ve}=0.4	σ_{vae}=0.5	σ_{c}=0.6	σ_{ve} =0.5	σ_{ve}=0.6	σ_{ve} =0.7
Changes in the impacts of energy efficiency improvements on sectoral employment if PCER=1						
Agriculture	-0.016	-0.018	-0.02	-0.022	-0.018	-0.015
Industry and mining	-0.056	-0.067	-0.077	-0.084	-0.067	-0.055
Transport	0.284	0.322	0.356	0.4	0.322	0.269
Services	0.114	0.125	0.135	0.155	0.125	0.105
Construction	-0.631	-0.710	-0.781	-0.884	-0.710	-0.593
Oil and gas extraction	0.135	0.154	0.171	0.191	0.154	0.129
Coal production	18.173	20.413	22.416	25.3	20.413	17.108
Oil products production	5.044	5.740	6.384	6.383	5.740	4.699
Gas production and distribution	0.783	0.879	0.966	1.093	0.879	0.736
Electricity production	0.703	1.110	1.476	1.382	1.110	0.927

***Source**: Authors' estimation.*

5. Conclusion

Energy efficiency improvement is one of the most important energy policies followed in many countries. This article focused on the electricity sector and attempted to examine the impacts of improvements in energy efficiency on the economy, particularly energy savings, and the associated greenhouse gas emission reductions.

Based on the results, it can be concluded that the impacts of energy efficiency improvements in the electricity sector are not limited to energy consumption; other variables, such as activity production, GDP, employment, and pollution, may also be affected. The results of this study showed that the impact of such improvements on GDP was positive, but limited in scenarios with lower energy efficiency. The export of oil products and natural gas increased in all scenarios and all price levels. Energy consumption by the electricity sector decreased, but the decrease was less pronounced in higher PSERs. This suggests that carbon revenues could have been recycled into the economy and changed the share of production and the inputs used, resulting in higher carbon emission due to the increase in energy demand.

The impacts of energy efficiency improvements on employment in different sectors were found to be dependent on the choice of technology in production. The closure rule and a fixed supply of primary factors allowed for factor mobility among sectors, leading to mixed results regarding employment in different sectors.

Most previous studies have focused on the effects of either energy price changes or energy efficiency improvements separately. It has been argued that a combination of energy policies that involve both energy efficiency improvements and environmental policies, such as carbon pricing with the revenues being recycled into the economy, can potentially have positive effects on both the economy and the environment simultaneously. Similar arguments have been put forward, emphasizing that policies designed to stimulate energy efficiency may have to be combined with other policies to discourage greater energy consumption (Schlomann & Eichhammer, 2014; Hanley et al., 2006).

This study provided evidence that energy efficiency improvements may be a cost-effective way to promote sustainable development, which, in turn, can reduce energy demand, decrease CO2 emissions, and spur economic growth. It is hoped that both policy- and decision-makers may pay more attention to the beneficial effects of carbon pricing and efficient use of natural resources on energy conservation. One way to enhance the improvements in energy efficiency is to implement effective climate policy, such as carbon pricing, and recycle the revenues raised into the economy to compensate for the adoption of new technologies. Further studies are recommended to investigate the macroeconomic effects of other energy efficiency alternatives, such as combined heat and power production, and new renewable energy technologies.

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Appendices

Appendix A. Description of the CGE model

Variables

ER	Real exchange rate
EG	Government expenditure
YG	Government revenue
EENR	Firm expenditure
YE	Firm revenue
GDTOT	Total volume of government consumption
FDTOT	Total volume of firm consumption
HSAV	Total household savings
GSAV	Government savings
ESAV	Firm savings
FSAV	Foreign savings
IADJ	Investment adjustment factor
OCAP	Outflow of capital
MPS	Marginal propensity to save for domestic non-government institutions
PQA_a	Activity prices
PD_c	Domestic prices
PM_c	Domestic price of imports
PE_c	Domestic price of exports
PQ_c	Composite commodity price
PVA_a	Value-added price by sector
$PDE_{ec,a}$	Energy input price
PVE_a	Aggregate energy input price
$PQINT_a$	Aggregate intermediate input price
PX_c	Aggregate producer price for commodities
QA_a	Level of activity a
QD_c	Quantity sold domestically of domestic output c
QE_c	Quantity of exports
QM_c	Quantity of imports
QQ_c	Composite goods supply
QX_c	Aggregated marketed quantity of domestic output of commodity
QF_{fa}	Quantity demanded of factor f from activity a
QFS_f	Labor supply by labor category (1000 persons)
QH_{ch}	Final demand for private consumption
$QINTA_a$	Aggregate intermediates
$QINT_{ca}$	Quantity of the commodity c as an intermediate input to activity a
$QINV_c$	Final demand for productive investment
$QVAE_a$	Value-added and energy composite
QVA_a	Value-added
QVE_a	Total energy inputs
$QFE_{ec,a}$	Energy inputs demand
WF_f	Average wage rate by labor category

$WDIST_{fa}$	Wage distortion factor for factor f in activity a
YFh_f	Income to the household from factor f
YH_h	Household income
YFE_f	Income to firms from factor f
EM_a	Emission of CO2 from activity
GDP	Gross domestic product
TEM	Total emissions of the economy
CDMR	Carbon revenues
PCER	Carbon price

Equations

1. $QVAE_a = iva_a.QA_a$
2. $QINT_{ca} = ica_{ca}.QA_a$
3. $PQA_a.QA_a = QVAE_a.PVAE_a + PQINT_a.QINT_a$
4. $QINT_{ca} = ica_{ca}.QINTA_a$
5. $QVAE_a = a_a^{vae}(\delta_a^{vae}.QVA_a^{-\rho^{vae}} + (1-\delta_a^{vae}).QVE_a^{-\rho^{vae}})^{\frac{1}{-\rho^{vae}}}$
6. $\frac{QVA_a}{QVE_a} = (\frac{PVE_a}{PVA_a}.\frac{\delta_a^{vae}}{1-\delta_a^{vae}})^{\frac{1}{1+\rho^{vae}}}$
7. $PVAE_a.QVAE_a = QVA_a.PVA_a + PVE_a.QVE_a$
8. $QVA_a = ad_a.\prod_f QF_{fa}^{\alpha_{fa}}$
9. $WF_f.WDIST_{fa}.QF_{fa} = QA_a.PVA_a.\alpha_{fa}$
10. $QVE_a = a_a^{ve}(\sum_{ec}\delta_a^{ve}.QFE_{ec,a}^{-\rho^{ve}})^{\frac{-1}{\rho^{ve}}}$
11. $QFE_{ec,a} = QVE_a(\frac{PDE_a}{PVE_a}.\frac{a_a^{ve\rho^{ve}}}{\delta_a^{ve}})^{\frac{-1}{1+\rho^{ve}}}$
12. $PVE_a.QVE_a = \sum_{ec} PDE_{ec,a}.QFE_{ec,a}$
13. $QQ_c = aq_c(\delta_c^q.QM_c^{\rho^q} + \left(1-\delta_c^q\right).QD_c^{\rho^q})^{\frac{-1}{\rho^q}} \in CM$
14. $\frac{QM_c}{QD_c} = (\frac{PD_c}{PM_c}.\frac{\delta_c^q}{(1-\delta_c^q)})^{\frac{1}{1+\rho^q}}$
15. $QQ_c = QD_c \;\; c \in CNM$
16. $QX_c = at_c(\delta_c^t.QE_c^{\rho^t} + (1-\delta_c^t).QD_c^{\rho^t})^{\frac{1}{\rho^t}} \;\; c \in CE$
17. $\frac{QE_c}{QD_c} = (\frac{PE_c}{PD_c}.\frac{1-\delta_c^{qt}}{\delta_c^t})^{\frac{1}{\rho^{t-1}}}$
18. $QX_c = QD_c \;\; c \in CNE$
19. $PM_c = pwm_c.ER.(1+tm_c)$
20. $PE_c = pwe_c.ER.(1+te_c)$
21. $PQ_c.QQ_c = (PD_c.QD_c + PM_c.QM_c)(1+tq_c)$
22. $PX_c.QX_c = (PD_c.QD_c + PE_c.QE_c)$
23. $\sum_c PQ_c.cwts_c = cpi$
24. $YF_{hf} = shry_{hf}.(\sum_f WF_f.WDIST_{fa}.QF_{fa} + trr_f.ER)$
25. $YH_h = \sum_f YF_{hf} + \sum_{ins} tr_{h,ins}$

26. $QH_{ch} = \frac{\beta_{ch}.(1-MPS_h).(1-ty_h).(1.sh_h).Y_h}{PQ_c}$
27. $YG = \sum_h ty_h . Y_h + \sum_{cm} tq_c . (PD_c . QD_c + PM_c . QM_c) + \sum_{cm} tm_c . ER . pwm_c QM_c + \sum_{ce} te_c . ER . pwe_c Qe_c + tr_{gov,row} . er + tr_{gov,insd}$
28. $YENT = \sum_f shry_{ent,f} . (\sum_f WF_f WDIST_{fa} . QF_{fa} + trr_f . ER) + \sum_{insd} tr_{ent,insd} + tr_{ent,row} . ER$
29. $QINV_c = \overline{IADJ} . qinv_c$
30. $HSAV = \sum_h MPS_h . (1 - ty_{h)}) . (1 - sh_h) . YH_h$
31. $GSAV = YG - \sum_c PQ_c . gles_c . gddtot + \sum_{ins} tr_{ins,gov}$
32. $ENTAV = YG - \sum_c PQ_c . e . entddtot + \sum_{ins} tr_{ins,ent}$
33. $QFS_f = \sum_a QF_{fa}$
34. $QQ_c = \sum_a QINT_{ca} + \sum_h qh_{ch} + PQ_c . gles_c . GDTOT + PQ_c . eles_c . entdtot + ID_c + DST_c$
35. $\sum_{cm} pwm_c . QM_c + \sum_f trf_f + \sum_{ins} tr_{row,ins} + OCAP = \sum_{ce} pwe_c . QE_c + \sum_f trr_f + \sum_{ins} tr_{ins,row} + FSAV$
36. $\sum_c QINV_c . PQ_c + OCAP + WALRAS = HSAV + GSAV + ENTSAV + FSAV . ER$
37. $GDP = \sum_a QA_a . PA_a$
38. $EM_a = \sum_{ec} QFE_{eca} . ef_{ec} . \frac{1}{CF_{eca}}$
39. $TEM = \sum_a EM_a$
40. $CDMR = PCER . (\sum_a EM0_a - \sum_a EM_a)$

Appendix B. Validation of the CGE model

The ability of the model to reproduce outcomes for endogenous variables using the true values of exogenous variables was examined. Due to the large number of model variables, only the validation test for the output of different sectors is presented here (some sectors were not included due to low values). The calculated numbers were very small, indicating that the designed model used for policy assessments was valid.

Validation of the CGE model

Sectors	The difference between the value of output before and after running the model (billion Rials)
Agriculture	0.05
Industry and mining	0.001
Transport	0. 2
Oil products production	0.001
Gas production and distribution	0.001
Electricity production	0.000