



An Assessment of Stabilization Policies in Conjunction with Energy Price Reform in Iran: Insights from a Dynamic Computable General Equilibrium (DCGE) Model

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Highlights

- An 18% annual electricity price hike (Scenario S1) generates immediate short-term negative impacts across most economic sectors.
- Long-term output diverges; energy-intensive industries and IT sectors remain under pressure despite partial recovery elsewhere.
- Gradual reform, combined with targeted tax relief and efficiency measures, is essential to sustain production stability and economic equity.

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Abstract

Pricing energy below its full economic cost creates allocative inefficiencies and undermines the fiscal sustainability of the energy sector, making energy price reform a crucial policy priority in many economies. However, such reforms can generate adverse short-run effects on economic activity and household welfare, highlighting the need for well-targeted stabilization measures. This study evaluates alternative complementary policies implemented alongside electricity price reform in Iran using a Dynamic Computable General Equilibrium (DCGE) model. In the baseline scenario, electricity prices increase by 18 % annually. Five tax-based stabilization policies are then assessed, covering taxes on labor income, capital income, factor demand, and output in the industrial and agricultural sectors. The results indicate that higher electricity prices contract output in the short run, particularly in energy-intensive sectors such as iron and steel, information technology (IT), and electricity. In contrast, some fossil fuel-dependent sectors benefit from substitution effects, while several sectors expand in the long run; nevertheless, adverse effects persist in selected modern industries. None of the examined fiscal policies fully offsets the negative effects of the electricity price shock. However, eliminating production taxes in agriculture and industry (S15) performs relatively better by partially mitigating output losses in key sectors. Moreover, S 15 and S 12 outperform the benchmark in reducing inflationary pressures and supporting GDP, although they reduce household consumption and welfare. Overall, the findings demonstrate that effective compensation requires policies tailored to the structural characteristics of the economy and appropriate sector-specific adjustment mechanisms over time.

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1. Introduction

Energy price reform has emerged as one of the most important economic policy issues in both developed and developing countries over recent decades. In many economies, energy prices have been maintained below their economic cost of supply for social, distributive, or political reasons. Although such policies may temporarily reduce household living costs and support productive activities, their persistence is often associated with a range of adverse consequences, including higher energy intensity, inefficient resource allocation, lower productivity, weakened incentives for investment in the energy sector, and increased fiscal pressures on governments (Bhattacharyya, 2019; IEA, 2024; IMF, 2024).

From a theoretical perspective, the electricity sector represents a classic example of a natural monopoly due to its substantial fixed costs, economies of scale, and network characteristics. In such industries, pricing mechanisms play a critical role in balancing economic efficiency, financial sustainability, and the continuity of investment. The classical literature on natural monopoly pricing demonstrates that deviations of prices from underlying economic costs can distort relative price signals, reduce allocative efficiency, and undermine the financial viability of public utility providers (Ramsey, 1927; Boiteux, 1956; Baumol & Bradford, 1970). More recent studies further emphasize that cost-reflective pricing is a necessary condition for ensuring energy security, expanding infrastructure, and mobilizing the financial resources required for long-term investment in the energy sector (Joskow, 2007; IEA, 2024).

The Iranian economy provides a prominent example of the challenges associated with pricing energy below its economic cost. Over the past decades, electricity tariffs and the prices of several other energy carriers have been set substantially below their economic cost of supply or opportunity cost. This pricing regime has contributed to excessive energy consumption, the expansion of implicit energy subsidies, growing imbalances within the energy sector, reduced investment capacity of energy suppliers, and increasing explicit and implicit fiscal liabilities for the government. In recent years, widening supply–demand imbalances in the electricity sector, coupled with insufficient financial resources for energy infrastructure development, have further highlighted the urgency of energy pricing reform (IEA, 2024; IMF, 2024).

Despite its potential long-term benefits, energy price reform is often associated with significant short-term economic and social adjustment costs. Higher energy prices can affect production, employment, and social welfare through several channels, including increased production costs, changes in firms' cost structures, reductions in households' real incomes, and upward pressure on the general price level. Consequently, the contemporary literature on energy economics and the political economy of reform emphasizes that the success of energy price reform depends critically on the design and implementation of appropriate stabilization policies capable of managing transitional adjustment costs and mitigating excessive economic fluctuations (Victor, 2009; Rentschler & Bazilian, 2017).

Although numerous studies have examined the economic impacts of energy price reform from the perspectives of macroeconomic variables and household welfare, a significant portion of this literature often restricts compensatory policies to simple transfer payments. These studies frequently overlook the simultaneous assessment of alternative stabilization tools and fail to compare their respective efficiencies in mitigating the adverse effects of such reforms. This research gap is particularly salient in the context of the Iranian economy, which grapples with the dual challenges of energy subsidies and sectoral energy imbalances. Designing alternative policy frameworks in such an environment necessitates a precise understanding of the transmission mechanisms affecting various economic sectors, as well as the identification of more cost-effective stabilization instruments. Accordingly, the novelty of the present study lies in two key dimensions: first, the design of an electricity price reform trajectory for the 2026–2050 horizon, aligned with macroeconomic environmental planning; and second, the evaluation of a comprehensive spectrum of stabilization policies to identify the most efficient policy mix for maintaining economic stability and curbing undesirable distributional impacts during the electricity price reform process.

Given the economy-wide nature of energy price reform and the complex interdependencies among economic sectors, Dynamic Computable General Equilibrium (DCGE) models provide an appropriate analytical framework for capturing both the direct and indirect effects of such policy interventions. These models allow for the simultaneous examination of interactions among markets, production sectors, households, and the government within a consistent economy-wide framework. Consequently, they offer a powerful tool for assessing the impacts of alternative policy scenarios on macroeconomic indicators, sectoral output, household welfare, and fiscal variables (Dixon & Jorgenson, 2013).

Against this background, the primary objective of this study is to evaluate alternative stabilization policies accompanying energy price reform in the Iranian economy using a Dynamic Computable General Equilibrium (DCGE) model. The analysis focuses on electricity price reform as one of the most critical components of the country's energy pricing system. Five alternative stabilization measures are examined, namely a labor income tax, a capital income tax, a tax on labor demand, a tax on capital demand, and a production tax applied to the industrial and agricultural sectors. By comparing the performance of these policy instruments, the study seeks to identify the most effective stabilization mechanisms for mitigating the transitional costs associated with energy price reform. The findings are expected to provide empirical evidence to support the design of complementary policy packages aimed at facilitating energy price reform while minimizing its adverse economic consequences in Iran.

The remainder of the paper is organized as follows. Section 2 presents the theoretical framework and reviews the relevant literature. Section 3 describes the model structure and research methodology. Section 4 introduces the data and policy scenarios. Section 5 reports and discusses the simulation results. Finally, Section 6 concludes and offers policy recommendations.

1.2 Stylized Facts

Data reported by the World Bank indicate that Iran exhibited a high level of energy intensity in 2015, with energy consumption amounting to 7.8 megajoules per constant U.S. dollar of gross domestic product (GDP). In comparison, the global average energy intensity was 5.13 megajoules per dollar, while the average for the Middle East and North Africa (MENA) region stood at 5.27 megajoules per dollar. Consequently, Iran's energy intensity was approximately 1.5 times the global average and 1.48 times the regional average, highlighting the economy's substantial dependence on energy inputs.

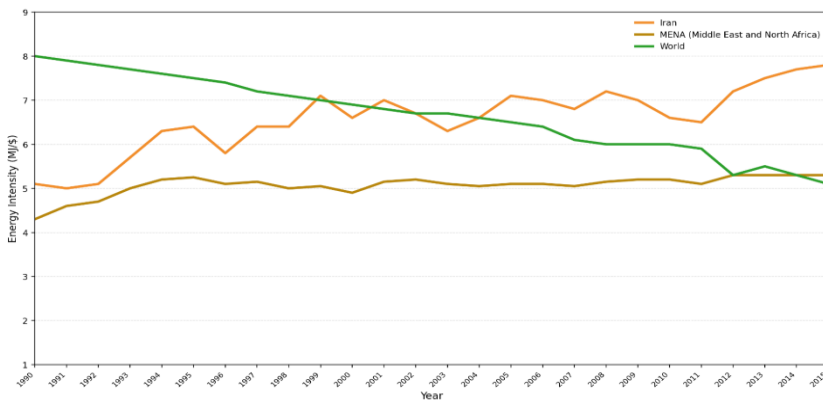


Figure 1. Trends in Energy Intensity: Middle East and North Africa (MENA) and Iran(1990–2015)

Source: Research Findings

According to statistics from Iran's electricity sector, average residential electricity consumption increased from 2,960 kWh per subscriber in 2018 to 3,028 kWh in 2019, representing a growth rate of 2.29 percent. During the same period, electricity consumption in the industrial sector reached 79.3 million MWh, reflecting an annual increase of 6.3 percent relative to 2018. Furthermore, in 2020, Iran allocated approximately USD 12.483 billion in electricity subsidies and ranked first among subsidy-providing countries, accounting for 24.15 percent of total global electricity subsidies.

A comparison of Iran's energy indicators with international benchmarks clearly demonstrates the need for electricity pricing reform. In 2020, Iran ranked first globally in terms of total energy subsidies and overall energy consumption, fourth in terms of the ratio of energy subsidies to GDP, and ninth in terms of per capita energy subsidies. In addition, electricity tariffs in Iran remained exceptionally low, particularly in the residential and commercial sectors, where average prices were approximately USD 0.003 and USD 0.004 per kWh, respectively. These figures were substantially below the corresponding global averages of USD 0.17 and USD 0.16 per kWh. Such a pricing structure not only

encourages excessive energy consumption but also imposes a considerable fiscal burden on the economy. Therefore, a gradual reform of electricity prices appears to be an essential prerequisite for enhancing economic sustainability and improving the efficient management of energy resources.

1.3 Trend of Electricity Prices in Iran

Figure 2 illustrates the evolution of average electricity tariffs in Iran over the period 1384–1402.

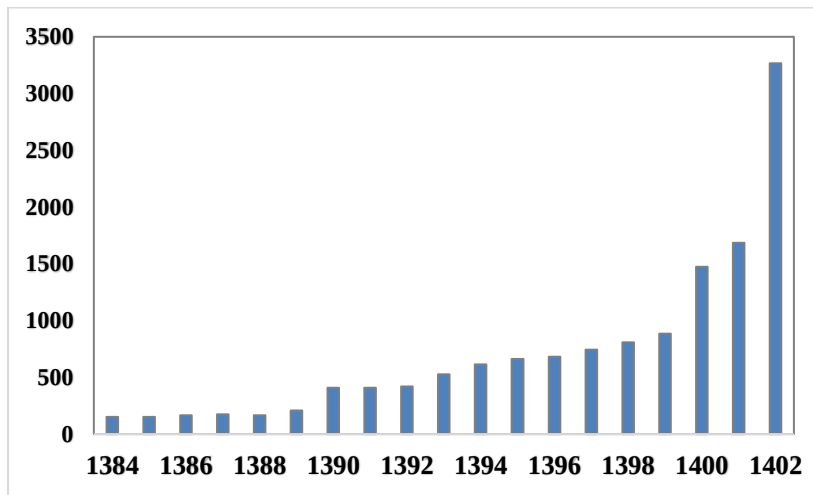


Figure 2. Average Electricity Tariff in Iran (Rials per kWh)

Source: Research Findings

Examining the temporal pattern of electricity prices is particularly important for understanding the persistence of price distortions, the magnitude of implicit subsidies, and the challenges associated with implementing electricity price reform in Iran.

As illustrated in Figure 1, electricity tariffs in Iran followed a distinct and non-linear trajectory over the period 1384–1402. At the beginning of the period, corresponding to the mid-1380s, average electricity prices across all consumer categories remained at very low levels and exhibited only limited variation. This relative stability largely reflected the continuation of extensive subsidy policies and the government's emphasis on maintaining low energy prices.

A major structural change occurred in 1389 following the implementation of the Subsidy Reform Plan. Electricity tariffs increased sharply across virtually all sectors, with average prices rising by approximately two to three times relative to the previous year. This substantial adjustment reflected the government's efforts to reduce energy intensity and move domestic energy prices closer to their economic cost.

During the subsequent period (1391–1396), the growth of electricity tariffs became more moderate, suggesting a phase of relative stabilization following the

initial reform shock. For instance, the average electricity tariff increased from approximately 409 rials per kWh in 1390 to around 683 rials per kWh in 1396, representing a cumulative increase of about 67 percent over six years, equivalent to an average annual growth rate of less than 9 percent. This period can be interpreted as a post-reform adjustment phase during which policymakers sought to contain energy-related inflationary pressures while limiting adverse welfare effects on consumers.

From 1397 onward, however, the pace of tariff adjustment accelerated again, culminating in a second wave of price increases after 1399. The average electricity tariff rose from approximately 884 rials per kWh in 1399 to 1,475 rials in 1400 and 1,685 rials in 1401, corresponding to an increase of nearly 90 percent within two years. An even more pronounced adjustment occurred in 1402, when the average tariff exceeded 3,000 rials per kWh, more than doubling its 1401 level. This sharp increase reflects renewed efforts to narrow the gap between administered electricity prices and the underlying costs of electricity supply.

Overall, the evidence indicates that the average annual growth rate of electricity prices during the period 1384–1402 was approximately 18 percent. This figure provides an empirical basis for the policy scenario adopted in the present study, where electricity prices are assumed to increase annually by 18 percent in the benchmark reform scenario.

2. Literature Review

2.1 Theoretical Background

2.1.1 Pricing in Natural Monopoly Industries and Energy Price Reform

Energy price reform has become one of the most important economic policy issues in countries characterized by extensive energy subsidies, high levels of energy consumption, and persistent financial imbalances in the energy sector. The theoretical foundations of such reforms can be traced to the literature on welfare economics, energy economics, and pricing theory in natural monopoly industries. The energy sector, particularly the electricity industry, is widely recognized as a classic example of a natural monopoly due to its high fixed costs, substantial economies of scale, extensive transmission and distribution networks, and limited scope for effective competition (Joskow, 2007). Under such conditions, prices cannot be determined solely through competitive market mechanisms. Instead, regulatory intervention and the design of appropriate tariff structures are required to balance economic efficiency, financial sustainability, and social objectives.

From the perspective of welfare economics, prices serve as fundamental signals for resource allocation and consumption decisions. When energy prices are set below their economic cost, consumers and producers receive distorted price signals, leading to excessive energy consumption, inefficient allocation of productive resources, and a decline in overall economic welfare. Persistent underpricing of energy may also weaken incentives for technological innovation, energy-efficiency improvements, and investment in energy infrastructure. Consequently, energy price reform is generally regarded as a necessary policy

instrument for restoring allocative efficiency and improving long-term economic performance.

The theoretical foundations of pricing in natural monopoly industries can be traced back to the seminal contributions of Ramsey (1927), Boiteux (1956), and Baumol and Bradford (1970). These studies demonstrate that prices should be designed in a manner that preserves economic efficiency while simultaneously ensuring the financial viability of public utility providers. Deviations of prices from the actual costs of energy supply can distort relative price signals, lead to inefficient resource allocation, and weaken incentives for investment in energy infrastructure.

Contemporary energy economics literature further emphasizes the importance of cost-reflective pricing for maintaining energy security, expanding infrastructure, and safeguarding the financial sustainability of the energy sector (Bhattacharyya, 2019). Recent reports by the International Energy Agency indicate that pricing energy below its economic cost not only contributes to excessive energy consumption and higher energy intensity but also undermines the financial capacity of energy companies and discourages investment in generation, transmission, and distribution infrastructure (IEA, 2024).

From this perspective, energy price reform can be viewed as an integral component of broader energy sector regulatory reform. Its primary objective is to align energy prices more closely with underlying economic costs, thereby improving allocative efficiency, strengthening investment incentives, and creating the conditions necessary for the long-term sustainability of the energy sector.

2.1.2. Energy Price Reform, Economic Efficiency, and Fiscal Sustainability

From a welfare economics perspective, prices perform their allocative function efficiently when they reflect the true opportunity cost of resources. In contrast, energy pricing below its economic cost leads to excessive energy consumption, distortions in resource allocation patterns, and a decline in social welfare.

Within the framework of public finance, energy subsidies are considered a form of government intervention that, while potentially pursuing distributive or social objectives, can impose substantial fiscal costs when maintained over time (Stiglitz & Rosengard, 2015). Empirical studies by the International Monetary Fund suggest that energy subsidies reduce economic efficiency, constrain government investment capacity, and weaken overall fiscal sustainability (Coady et al., 2019).

In the recent energy economics literature, the concept of quasi-fiscal imbalance has been introduced to describe situations in which a significant portion of subsidy costs is borne by state-owned energy enterprises outside the formal government budget (World Bank, 2023). Under such conditions, the gap between administered energy prices and actual economic costs is reflected in rising debt levels, liquidity constraints, and declining investment capacity within energy firms. The IMF further emphasizes that these imbalances ultimately translate into

implicit government liabilities, thereby undermining the fiscal sustainability of the public sector (IMF, 2024).

Therefore, energy price reform not only enhances allocative efficiency but also contributes to reducing implicit subsidies, improving the financial position of energy utilities, and strengthening overall fiscal sustainability.

2.1.3. Stabilization Policies Accompanying Energy Price Reform

Although energy price reform is well justified from the perspectives of economic efficiency and fiscal sustainability, its implementation is typically associated with significant short-term economic and social costs. Increases in energy prices may adversely affect production, employment, and social welfare through higher production costs, reductions in households' real income, and upward pressure on the general price level.

The theoretical foundation for the need for stabilization policies can be traced to the theory of the second-best. According to Lipsey and Lancaster (1956), in an economy characterized by multiple distortions and structural constraints, the removal of a single distortion does not necessarily lead to an improvement in overall social welfare. Accordingly, energy price reform should be complemented by policy measures capable of managing the transitional and short-run adjustment costs associated with such reforms.

The recent literature on energy reform further emphasizes that the success of energy price liberalization depends critically on the design of appropriate compensatory and stabilization policies (Rentschler & Bazilian, 2017). Such policies may include tax restructuring, targeted transfer payments, support for productive activities, or strengthening social protection systems, all of which aim to mitigate the short-term adverse effects of reform while preserving its long-term efficiency gains.

In addition, in resource-rich economies, cheap energy often functions as part of a broader rent distribution mechanism, and increases in energy prices may therefore face significant social and political resistance (Beblawi & Luciani, 1987). In such contexts, stabilization policies also play a crucial role in enhancing the political feasibility and social acceptability of reform programs. These measures may include targeted cash transfers, expansion of social safety nets, reductions in distortionary taxes on productive sectors, or investment in public infrastructure. The common objective of these policies is to preserve the long-term benefits of energy price reform while reducing its short-term adjustment costs.

2.1.4. General Equilibrium Framework and the Rationale for Using a DCGE Model

Energy price reform and the implementation of stabilization policies simultaneously affect households, firms, the government, and the external sector of the economy. Increases in energy prices can influence production cost structures, real household income, government tax revenues, and the pattern of international trade. Similarly, stabilization policies operate through changes in the

tax structure, income transfers, and public expenditure, thereby affecting overall economic performance.

From a general equilibrium perspective, the economy is a system of interrelated markets in which a shock in one market can propagate across all other markets (Arrow & Debreu, 1954). Accordingly, partial equilibrium approaches are unable to capture the full range of direct and indirect effects associated with energy price reform and accompanying stabilization policies.

Dynamic Computable General Equilibrium (DCGE) models provide a suitable framework for addressing these limitations by enabling the simultaneous analysis of behavioral responses of households, firms, the government, and the external sector to policy changes over time (Dixon & Jorgenson, 2013). As a result, DCGE models offer a comprehensive analytical structure for evaluating energy price reform and stabilization policies, and for assessing their impacts on production, consumption, investment, household welfare, and key macroeconomic variables.

2.2 Empirical Literature Review

2.2.1 Domestic Studies

Khiabani (2008) investigates the effects of energy carrier price reforms in Iran under three alternative scenarios: (i) an increase in gasoline prices, (ii) an increase in the prices of all energy carriers, and (iii) an increase in all energy carrier prices aligned with international price levels. The results indicate that energy price increases reduce distortions in relative prices and lead to lower excessive energy consumption in both production sectors and households. However, higher energy prices also raise production costs, increase inflation, and reduce the welfare of low-income groups. The study further shows that both inflationary pressures and welfare losses are more pronounced under the second scenario compared to the first.

Sadeghi et al. (2010) examine the impact of energy price increases on three key macroeconomic variables—GDP growth, inflation, and private consumption—over the period 1991–2007. Their findings suggest that energy price reform leads to a decline in economic growth and private consumption, while simultaneously increasing the inflation rate.

Eslami Andargoli et al. (2011) analyze the welfare effects of cash-based energy subsidy reforms in the Iranian economy. Their results indicate that increases in energy prices combined with cash transfer schemes lead to a significant reduction in GDP and induce economic recessionary pressures. Moreover, financing these transfers through government budget surpluses, value-added taxes on electricity, or household income taxes further exacerbates the decline in output.

Dargahi and Ghorbannazadeh (2012) examine the effects of energy price increases and the implementation of government compensatory policies on key macroeconomic variables in Iran. Their results indicate that economic growth declines under both scenarios: (i) energy price increases without compensatory

policies, and (ii) energy price increases accompanied by compensatory measures. However, when productivity improvements are introduced in addition to compensatory policies, economic growth improves relative to the previous cases. Inflation, by contrast, increases in all scenarios. These findings suggest that the success of energy price reform depends critically on the implementation of targeted compensatory policies on the one hand, and supply-side measures aimed at improving productivity in the production sector on the other.

[Rahiminia and Akbari-Moghaddam \(2016\)](#) simulate ten alternative scenarios involving gradual reductions in indirect energy subsidies combined with cash transfers to households, firms, and the government, in order to assess the distributional effects of subsidy reform. Their results show that in all scenarios, welfare inequality across households declines and overall welfare equity improves.

[Azarm and Bakhshoodeh \(2019\)](#) investigate the effects of energy price increases for diesel and electricity under different scenarios within the framework of Iran's subsidy targeting program. The study analyzes input relationships and returns to scale in production. The results indicate that electricity price increases have a more pronounced impact than diesel price increases, leading to higher production costs, lower output, reduced profits, and consequently lower welfare for wheat producers.

[Madani-Zadeh and Ebrahimiyan \(2020\)](#) examine the effects of energy price reform combined with the redistribution of generated revenues on key macroeconomic variables. Their findings indicate that, in addition to reducing energy intensity at both household and firm levels, average welfare increases overall, with most of the gains occurring in the short run due to higher purchasing power and increased household consumption. However, in the medium and long run, labor supply reductions induced by cash transfers lead to declines in output and capital accumulation.

[Sadeghi Hassanvand et al. \(2020\)](#) investigate the impact of energy price increases on welfare, poverty, and the distribution of household expenditures in rural areas over the period 1988–2017. Their results show that higher energy prices reduce rural household welfare. Nevertheless, government compensatory policies mitigate the magnitude of welfare losses. The study also finds a negative relationship between energy price increases and the poverty line, while compensatory policies contribute to improved expenditure distribution and reduced inequality.

[Mohammadi-Pour et al. \(2021\)](#) analyze the macroeconomic effects of energy price reform on key variables of the Iranian economy. Their results suggest that a positive energy price shock leads to persistent negative effects on household consumption, firm investment, non-oil output, and total output, with adverse impacts lasting for up to 30 periods. Moreover, investment declines significantly during the first nine periods before gradually stabilizing after approximately 25 periods, highlighting the potentially long-lasting adjustment costs associated with energy price reforms.

Abbaszadeh (2022) examines the impact of energy carrier prices and industry size on firm-level investment over the period 2009–2018. The results indicate that energy prices have a negative effect on industrial investment; however, this effect is relatively small. In contrast, the positive effect of industry size dominates, leading to a net positive interaction effect between industry size and energy prices on current investment. Additionally, lagged investment in financial markets exerts a positive influence on current industrial investment.

Mohsenpour et al. (2023) analyze energy costs in key Iranian industries, including steel, cement, refining, agriculture, automotive, machinery, and food sectors. Their findings indicate that the petrochemical, cement, and refining industries exhibit the highest sensitivity to energy cost increases under two price shock scenarios (50% and 100% increases). In contrast, the automotive and agricultural sectors are identified as relatively less vulnerable to energy price reforms. Accordingly, the study suggests that energy price liberalization in less sensitive industries may represent a feasible policy option with comparatively limited adverse macroeconomic consequences.

Shahbazi et al. (2024) examine the impact of energy price changes on energy intensity in mineral products under two scenarios: (i) a 5% price shock to natural gas and (ii) a 5% price shock to oil, over a projection horizon extending to 2050. The results show that under the first scenario, energy efficiency improves steadily and energy intensity remains persistently negative. In the second scenario, energy intensity initially increases but gradually declines over time, indicating a short-run rise followed by long-run improvements in energy efficiency within the mineral sector.

Izadi et al. (2026) assess the welfare effects of electricity price reform under four different pricing adjustment scenarios. Their results indicate that equivalent variation (EV) is negative in the first three scenarios but becomes positive in the fourth scenario. In other words, rapid increases in electricity prices lead to welfare losses, whereas a gradual and moderate price adjustment improves overall welfare. The decomposition of welfare effects further shows that terms of trade, technological change, demographic factors, allocative efficiency, and non-market endowments are the main contributors to welfare improvements.

2.2.2. International Studies

Silva et al. (2009), examine the welfare impacts of substantial electricity tariff increases in Montenegro. Their results indicate that such price adjustments impose significant economic pressure on low-income households by substantially increasing their energy expenditures. The study also highlights potential environmental implications, as vulnerable households tend to shift toward greater use of solid fuels such as firewood, thereby exacerbating environmental degradation. The authors conclude that tariff reforms should be accompanied by appropriate social protection policies to mitigate adverse distributional and environmental effects.

Akkemik and Oğuz (2011), investigate the effects of full electricity market liberalization in Turkey using a simulation-based framework. Their findings suggest that market liberalization improves efficiency in the electricity sector, reduces energy prices for households, and increases overall economic welfare by approximately 0.5 to 1.1 percent of GDP. However, the study also emphasizes that institutional constraints and political pressures may hinder the full realization of these efficiency gains. Moreover, while electricity price reductions negatively affect the electricity generation and transmission sectors, they have positive spillover effects on electricity-dependent industries.

Solaymani and Kari (2014), analyze the macroeconomic impacts of energy subsidy reform in Malaysia. Their results show that such reforms increase real GDP and investment, while simultaneously reducing total exports and imports. The elimination of energy subsidies also leads to a decline in aggregate energy demand and a reduction in carbon emissions. However, households experience a significant decrease in consumption and welfare. The transport sector is particularly affected, as higher input costs—driven by increased energy prices—reduce output and exports, while increasing imports of transport-related goods.

Sun (2015), shows that a tiered electricity pricing reform scheme has been effective in encouraging household electricity conservation and reducing cross-subsidization distortions embedded in tariff structures. However, the responsiveness of households across different income groups is found to be heterogeneous and influenced by multiple socioeconomic factors. The study concludes that future policy design should focus on improving the precision of such pricing mechanisms and complement them with targeted supportive measures to simultaneously enhance efficiency and equity.

Zhang (2015), examines the welfare effects of a more than 50% increase in residential electricity tariffs in Turkey in 2008. The results indicate that high-income households are approximately three times more responsive to price changes compared to low-income households. Nevertheless, the welfare loss, measured as the reduction in consumer surplus relative to income, is 2.9 times higher for the lowest income quintile than for the richest quintile. This finding suggests that despite stronger behavioral responses among wealthier households, the economic burden of tariff increases disproportionately falls on poorer households.

Berton and Mirzapour (2016), investigate the welfare implications of energy subsidy reforms, particularly for fossil fuels. Their results suggest that while subsidy removal frees up fiscal resources, the main challenge lies in public acceptance of new price levels, especially among vulnerable households. Despite widespread recommendations for direct compensation mechanisms, recent experience in Iran indicates that such mechanisms may face sustainability challenges over time. Using a simplified model, the authors demonstrate that the feasibility of subsidy reform critically depends on parameters such as the initial subsidy rate and the share of energy in household consumption baskets, particularly when general equilibrium price effects are considered.

Capros et al (2016), assess the macroeconomic and sectoral impacts of higher energy prices in the European Union relative to non-EU countries up to 2050. Their simulation results show that higher energy prices in the EU reduce EU GDP relative to the baseline scenario. The cumulative effect ranges between 0.02% and 0.41% over the period 2015–2050, with tax policies and the electricity generation mix identified as key determinants of macroeconomic outcomes.

Gelan (2018), analyzes the economic and environmental effects of electricity subsidy reductions in Kuwait under two scenarios. In the first scenario, a 30% reduction in electricity subsidies leads to adverse macroeconomic effects across most endogenous variables, while simultaneously generating environmental benefits through lower CO₂ emissions. GDP and household welfare decline under this scenario. In the second scenario, subsidy reductions are accompanied by compensatory cash transfers. The results indicate that such transfers mitigate the negative macroeconomic impacts, reduce emissions further, and improve both GDP and household welfare relative to the uncompensated scenario.

Ross and Adams (2020), examine the gradual elimination of domestic subsidies for refined petroleum products and electricity in Gulf Cooperation Council (GCC) countries, with a particular focus on Saudi Arabia following the 2014 collapse in global oil prices. Their findings indicate that subsidy removal improves allocative efficiency by eliminating a major economic distortion. Although employment and capital decline in most years, real GDP increases over time. The study also shows that fully funded compensatory transfers can neutralize the adverse effects of higher energy prices and result in only minimal impacts on national welfare.

Jamil et al (2022), investigate the socio-economic impacts of electricity sector reforms in Pakistan since 1992, including the entry of independent power producers (IPPs). The study evaluates the effects on government, private sector actors, and consumer groups. The results suggest that while the primary benefit of the reforms has been the timely expansion of generation capacity, they have also led to significant increases in environmental costs and electricity production costs. Overall, the reforms generate a net welfare loss for both consumers and the government, thereby reducing social welfare. The authors conclude that stronger regulatory frameworks could have produced more favorable outcomes for stakeholders.

Jia et al (2022), analyze electricity market reforms in China under the long-term goal of carbon neutrality, in a context where prices remain partially regulated and approximately 70% of electricity is generated from thermal power plants. Simulation results suggest that achieving carbon neutrality may increase energy costs, raise demand for labor and capital, and reduce GDP. However, electricity market reforms significantly improve the overall energy and economic structure while reducing government fiscal deficits.

Amin et al (2022), examine the effects of decarbonization policies, including carbon taxation and the removal of fossil fuel subsidies and internal electricity price distortions. Their findings indicate that all policy scenarios can generate a win-win outcome in terms of macroeconomic performance and CO₂ emissions

relative to the baseline scenario characterized by price distortions and the absence of carbon taxation.

Wang and Wang (2023), propose a novel integrated framework to assess electricity market reforms by decomposing energy efficiency into production efficiency and consumption efficiency. Their results show that energy efficiency remains relatively low across most Chinese provinces, with production-side efficiency generally lower than consumption-side efficiency. Moreover, electricity market reforms have no statistically significant effect on production efficiency, while they significantly and persistently improve consumption-side energy efficiency.

Turco et al (2023), analyze the economic and distributional effects of alternative macroeconomic stabilization policies in response to energy price shocks. Their results show that, in the absence of compensatory policies, increases in fossil fuel prices lead to higher inflation, lower GDP, and slower economic growth. While reductions in general taxation and household subsidies have limited effects, corporate subsidies can accelerate recovery in the short run but generate fiscal instability and a subsequent downturn in the medium term. The study finds that timely reductions in energy tariffs financed by government budgets are the most effective policy in mitigating GDP losses at relatively low fiscal cost, particularly when combined with taxation of windfall profits in the energy sector.

Xin-Gang et al (2024), examine the economic, energy, and environmental effects of carbon emissions trading systems and electricity market reforms, focusing on market structure and pricing mechanisms. Their findings suggest that the two policy instruments exhibit strong synergies in optimizing industrial structure, improving energy consumption patterns, and reducing carbon emissions. However, imperfectly competitive market structures perform better than fully competitive markets in terms of energy consumption restructuring and emission reductions. Furthermore, regulated electricity pricing is found to be more beneficial than full price liberalization in terms of GDP growth and household disposable income.

Zhang et al (2025), examine the transmission mechanisms through which electricity price fluctuations affect key macroeconomic variables within an integrated system. Their results indicate that increases in average prices of both thermal and clean electricity have a negative effect on economic growth, while simultaneously improving energy efficiency. In addition, higher thermal electricity prices significantly reduce carbon emissions in industrial sectors, whereas increases in clean electricity prices partially offset emission reduction efforts. The study further shows that the impact of thermal electricity prices on the energy–economy–environment system is substantially stronger than that of clean electricity prices.

Feng et al (2025), demonstrate that the removal of energy subsidies, in the absence of compensatory mechanisms, reduces CO₂ emissions but increases poverty levels in developing countries. However, when the revenues from subsidy

removal are redistributed through social protection programs targeting lower-income households, overall poverty is reduced. At the same time, full redistribution may partially offset the initial environmental gains by increasing energy consumption and emissions.

A large strand of the existing literature has focused primarily on the aggregate effects of energy price reform, while treating accompanying stabilization policies largely as simple cash transfer mechanisms. As a result, the simultaneous evaluation of alternative stabilization and compensatory instruments alongside electricity price reform has been largely overlooked. Accordingly, the main contribution of the present study is twofold. First, it develops an electricity price adjustment path consistent with long-term planning horizons up to 2050, aligned with broader environmental and energy policy objectives. Second, it provides a comparative assessment of a wide range of stabilization policy instruments within a Dynamic Computable General Equilibrium (DCGE) framework in order to identify the most effective policy mix for maintaining macroeconomic stability during the process of electricity price reform.

3. Research Methodology

3.1 The Global Trade Analysis Project (GTAP) Model¹

To quantitatively evaluate the research objectives, this study employs the GTAP-E-Power model, a specialized extension of the Computable General Equilibrium (CGE) framework. CGE models serve as sophisticated econometric tools designed to simulate the multi-sectoral impacts of policy, technological, or economic shocks on both national and global economies. By representing the economy as an interconnected system of markets and economic agents, including households, firms, government, and the foreign sector, these models analyze inter-sectoral interactions under general equilibrium conditions (Marzban & Nejati, 2012). The GTAP project provides the standardized structural framework for this CGE modeling.

In the GTAP architecture, regional households function as the primary owners of production factors. Their total income is derived from factor endowments (e.g., labor and capital) combined with aggregate taxes and tariffs. Following income realization, household expenditure is allocated among savings, private consumption, and government transfers, governed by a Cobb-Douglas utility function. A key structural nuance in this model is the application of a non-homothetic utility function for private consumption; unlike the government's consumption functions, which maintain constant expenditure shares, the non-homothetic specification allows for varying expenditure shares across different goods as income levels fluctuate.

On the production side, firms combine primary factors (labor and capital) and intermediate goods to generate output. The model assumes perfect competition, constant returns to scale, and full factor mobility across sectors, with the exception

¹ Global Trade Analysis Project

of land and natural resources. All endogenous variables, including sectoral output, factor demands, trade volumes (exports/imports), and price levels, are determined within the model's equilibrium framework. By incorporating the energy factor and accounting for carbon dioxide emissions associated with fossil-fuel consumption, the GTAP model is equipped to evaluate environmental policies and is consequently known as the extended GTAP-E model. Within this framework, energy is represented by five distinct carriers, gas, crude oil, electricity, coal, and petroleum products. On the production side, firms may use these energy carriers as inputs in addition to intermediate goods and primary factors, such as labor and capital. Moreover, these energy carriers form part of the consumption bundles of households and the government (Burniaux and Truong, 2002).

3.2 The GTAP-E Extension

The GTAP-E (Energy and Environment) model is an advanced iteration of the standard GTAP framework, specifically engineered to integrate energy and environmental considerations (Burniaux and Truong, 2002). By utilizing an input-output matrix to ensure accounting consistency between total inputs and outputs across all economic sectors, the GTAP-E model enables a rigorous analysis of environmental policies, such as carbon taxes, subsidies, and tariff adjustments. The model captures the reallocation of resources resulting from changes in relative prices and the substitution of inputs within the production structure. Furthermore, it facilitates the assessment of how international trade policies and tariff shifts influence inter-country production and trade balances (Nong et al., 2021).

3.3 The GTAP-E-Power Specification¹

This study utilizes the GTAP-E-Power model, a further refinement of the GTAP-E that incorporates advanced electricity generation technologies and carbon dioxide emission pathways, making it highly suitable for climate change and energy policy analysis. Recognizing that electricity is a critical driver of modern economic growth, often accompanied by greenhouse gas emissions, the GTAP-E-Power model introduces the capacity for detailed electricity substitution (Nung, 2020).

A significant departure from the standard GTAP-E is the replacement of the “virtual electricity” commodity with a highly granular electricity sector. In the GTAP-E-Power framework, electricity is modeled as a complex composite of various generation and distribution components, including: transmission and distribution, nuclear, coal, gas (both peak and off-peak generation), oil-based generation (peak and off-peak), hydroelectricity, and renewable sources such as wind and solar (Peters, 2016). This high-resolution specification allows for a more precise simulation of the transition toward sustainable energy mixes and the impacts of electricity-specific policy interventions.

¹ The mathematical formulations of this model are provided in the Appendix

4. Data and Scenario Design

In this research, all substitution elasticities within the nested production and consumption structures were specified and analyzed using Version 11 of the GTAP database. Released in 2024, the GTAP database (Version 11) encompasses 160 regions and 65 sectors, thereby providing a comprehensive coverage of the global economy. This database consists of two principal components: first, coefficients derived from the Social Accounting Matrix (SAM); and second, the model's behavioral parameters, including substitution elasticities. These parameters are reported within the GTAP framework and are calibrated in accordance with empirical literature and established calibration procedures, such as the studies by [Burniaux and Truong \(2002\)](#), [Peters \(2016\)](#), and [Hertel \(1997\)](#). Consequently, the analysis was conducted using RunDynam software, utilizing these standard and well-documented GTAP parameters.

In line with the objectives of the study, the data are aggregated into three regions (Iran, developed countries, and developing countries), 11 sectors, and five primary production factors, including skilled labor, unskilled labor, natural resources, land, and capital, as well as five energy carriers.

Table 1. Data Aggregation Based on the 2017 Social Accounting Matrix

Set	Before Aggregation	After Aggregation
Regions	160 regions	Iran, developed countries, developing countries
Economic Sectors	65 sectors	Agriculture; coal; oil; gas; energy-intensive sectors; other manufacturing sectors; petroleum products; iron and steel; information and communication technology; electricity; services
Production Factors	8 factors	Land; skilled labor; unskilled labor; capital; natural resources
Energy Carriers	5 carriers	Coal; oil; gas; petroleum products; electricity

Source: Research findings

Scenario Design In this study, to simulate the future trajectory of electricity prices in Iran, the historical growth rate of electricity prices is first examined. The results indicate that the average annual growth rate of electricity prices over the period 2005–2023 (1384–1402) is approximately 18 percent. Accordingly, in order to evaluate the effects of electricity price reform, the first scenario applies an 18 percent annual increase in electricity prices.

In the second step, to mitigate the adverse effects of electricity price increases, a set of accompanying compensatory policy scenarios is introduced alongside the price shock. The combination of these scenarios with the baseline price increase scenario enables a more comprehensive assessment of the stabilizing role of fiscal policy in the presence of rising electricity prices. The full set of scenarios is presented in Table 2.

Table 2. Set of Policy Scenarios

Scenario	Scenario Code	Description	Policy Instrument	Objective	Theoretical Expectation
1	S ₁ as the baseline scenario (REF)	Electricity price reform without complementary policies, involving an 18% increase in electricity prices based on the average of the preceding 18-year period	Increase in electricity tariffs	Improving the efficiency of resource allocation; reducing excessive energy consumption; enhancing energy efficiency; restructuring production; improving energy security; encouraging investment in the energy sector; reducing the fiscal burden of energy subsidies; increasing government revenue; and reducing the budget deficit	More efficient use of electricity and changes in electricity consumption behavior; reduction in explicit and implicit energy subsidies, particularly electricity subsidies; increased investment in the electricity sector; reduced electricity consumption and losses; and enhanced security of electricity supply
2	S ₁₁	REF + elimination of labor income tax	Reduction in labor income tax	Increasing disposable income and labor supply	Increasing consumption and employment through higher household income and lower labor costs, thereby supporting the objectives of energy-price reform, particularly electricity-price reform
3	S ₁₂	REF + elimination of capital tax	Reduction in capital tax	Stimulating investment	Increasing capital accumulation and output by reducing investment costs, particularly in the electricity sector
4	S ₁₃	REF + elimination of the tax on labor demand	Reduction in the tax on labor demand	Reducing hiring costs	Increasing labor demand and output through lower hiring costs for firms, particularly in the electricity sector
5	S ₁₄	REF + elimination of the tax on capital demand	Reduction in the tax on capital demand	Reducing the cost of capital	Stimulating investment and production capacity by reducing the user cost of capital, particularly in the electricity sector
6	S ₁₅	REF + elimination of output taxes on agriculture and industry	Reduction in output taxes on the agricultural and industrial sectors	Supporting agricultural production and supporting and strengthening industrial production	Increasing output and employment in the agricultural and industrial sectors by reducing the cost pressures arising from energy-price reform, lowering production costs, and enhancing competitiveness

5. Simulation Results

Analysis of the sectoral impacts of electricity price reform scenarios Under Scenario S_1 , over the period 2026 to 2050, the increase in electricity prices leads to changes in relative prices across the entire economy, thereby affecting the economic behavior of production agents, including firms and households. This framework enables the assessment of sectoral sensitivity and responses to price shocks, providing a more detailed understanding of the transmission mechanisms through which electricity price increases propagate within the economic structure. Figure 2 illustrates the effects of electricity price reform on various production sectors of the Iranian economy, including agriculture, coal, oil, gas, energy-intensive industries, non-energy-intensive industries, petroleum products, iron and steel, information and communication technology, electricity, and services, under Scenario S_1 over the specified time horizon.

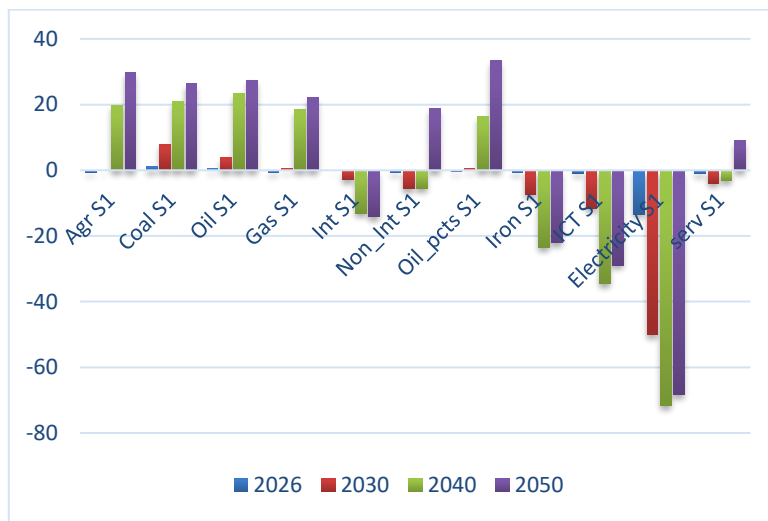


Figure 3. Output of different economic sectors under scenario S_1 over specified years

Source: Research findings

The results indicate that in 2026, all sectors except oil and coal experience a decline in output following the increase in electricity prices. The substantial reduction in electricity sector output (approximately 13 percent), along with the decline in industrial production, suggests that the economy has not yet developed efficient adjustment mechanisms or a smooth transition toward energy efficiency. This initial contraction may be attributed to the low short-run elasticity of substitution between energy and other production inputs. The slight expansion in the oil and coal sectors reflects a partial substitution toward traditional energy sources in response to higher electricity costs. At this stage, the effects are predominantly contractionary and represent an initial system adjustment.

By 2030, electricity production declines by more than 50 percent, while services, information and communication technology, iron and steel, energy-intensive industries, and non-energy-intensive industries also experience significant reductions in output. This suggests a structural restructuring of production, with reduced activity in electricity-dependent sectors across the economy. This year can be considered a critical turning point in the reform process. At the same time, positive growth in oil, gas, petroleum products, and coal indicates that fossil fuels absorb a larger share of energy demand as substitutes for electricity. In the absence of complementary environmental policies, this may lead to increased pollution and greater reliance on fossil fuels. Signs of structural adjustment become more evident from 2040 onwards. Agriculture and fossil-fuel-based sectors (oil, petroleum products, coal, and gas) experience notable growth, while electricity output reaches its most significant decline over the entire period. This stage reflects a reallocation of resources away from electricity-intensive industries and services toward sectors with lower electricity dependency or higher substitutability with alternative energy carriers. Consequently, serious environmental concerns may arise. Services and non-energy-intensive industries show only modest growth, while energy-intensive industries, iron and steel, and ICT continue to face persistent cost pressures. The increase in agricultural output suggests a shift of capital and labor toward more traditional, less electricity-intensive activities. Overall, these trends indicate a gradual deviation of the economic structure from a technology-driven and knowledge-based development path.

By 2050, final adjustment patterns emerge. Significant growth in agriculture, coal, oil, gas, non-energy-intensive industries, petroleum products, and services indicates a new equilibrium in which the economy has partially adapted to higher electricity prices. Although iron and steel and ICT sectors remain under pressure, their decline is less pronounced compared to 2040. Electricity sector output improves from -71.59 to -68.2 , indicating a partial stabilization. Only energy-intensive industries continue to experience a persistent decline in output. These findings emphasize that electricity price increases alone, without accompanying compensatory policies, may shift the economic structure toward a less innovative and more fossil-fuel-dependent trajectory. Therefore, alongside price reforms, the government should implement complementary policies to mitigate adverse effects and ensure sustainable economic growth.

Supportive policy scenarios: To offset the negative consequences of price reform, a set of fiscal policy instruments is considered, including taxes on labor income, capital income, labor demand, capital demand, and production in agriculture and industry. A comparison of average output growth across these scenarios over the period 2026–2050 provides a clear picture of the effects of tax-based stabilization policies.

Interpretation of Table 3: Effects of Stabilization Policies

Based on Table 4, the effects of different stabilization policies can be interpreted across sectoral groups, with a focus on deviations from Scenario S_1 . Agricultural sector (Agr) Under Scenario S_1 , the average output growth in the agricultural sector is 14.68 percent over the period. Under Scenario S_{15} , a slight increase in output is observed. Although this increase is marginal, it may reflect the impact of reduced tax burden on this sector. In contrast, Scenario S_{12} leads to a decline in output. In the remaining policy scenarios, no significant differences are observed, suggesting that substitution effects through income and capital channels are limited in agriculture.

Table 3. Comparison of Average Sectoral Output Growth under Different Policy Scenarios (percent)

Sector	S_1	S_{11}	S_{12}	S_{13}	S_{14}	S_{15}
Agr	14.682	14.6812	10.5212	14.68	14.578	14.726
Coal	16.6084	16.6084	19.5104	16.6072	16.7352	33.4516
Oil	17.064	17.0632	14.1164	17.062	17.0048	15.0376
Gas	12.8032	12.802	10.6992	12.8012	12.7776	12.2276
Energy-intensive industries (Int)	-9.8464	-9.8468	-9.2924	-9.8476	-9.7976	5.358
Non-energy-intensive industries (Non_Int)	-0.8592	-0.8588	-1.3944	-0.8608	-0.832	13.5008
Petroleum products	13.6168	13.6168	13.1884	13.6156	13.6412	28.1072
Iron and steel	-17.372	-17.3728	-16.2712	-17.374	-17.3036	-6.4036
ICT	-25.1008	-25.1012	-22.4584	-25.1016	-24.9748	-5.4984
Electricity	-61.076	-61.0768	-64.3636	-61.078	-61.1536	-60.9996
Services	-1.1876	-1.1884	0.1388	-1.1896	-1.1108	-0.5476

Source: Research findings

Fossil fuel sectors (Coal, Oil, Gas, Petroleum products) Although the magnitude of responses varies across sub-sectors, this group benefits most from fiscal policy interventions. In the coal sector, reductions in capital taxation (S_{12}) and production taxation (S_{15}) generate the strongest output gains. Under Scenario S_{12} , average coal output increases from 16.6 percent to approximately 19.5 percent, while under Scenario S_{15} it rises to 33.45 percent. This suggests that such policies stimulate fossil-fuel-based production activities.

In oil, gas, and petroleum products, the effects of S_{11} , S_{12} , and S_{13} are broadly similar in direction. Under S_{15} , oil and gas output slightly declines, while petroleum products experience an increase. Energy-intensive and non-energy-intensive industries (Int and Non_Int) In this study, the industrial sector is divided into energy-intensive and non-energy-intensive sub-sectors. In both groups, tax reforms are unable to reverse the negative structural impact of higher electricity prices. Under all supportive scenarios except S_{15} , average output growth remains negative (approximately between -1 and -9 percent), indicating a substantial decline in industrial activity. However, under Scenario S_{15} , both sub-sectors

experience positive growth, suggesting that production-based tax relief is more effective than income- or capital-based measures. Iron and steel sector (Iron) Given the strategic importance of iron and steel and its high energy intensity, particularly electricity consumption, this sector is analyzed separately. Across all scenarios, a decline in output growth is observed. Only under Scenario S15 is the magnitude of decline reduced. This indicates that tax reductions alone are insufficient to offset the impact of electricity price shocks, as electricity cost dominates the cost structure of this sector. Information and Communication Technology (ICT) In the ICT sector, which experiences a substantial decline of approximately 25 percent under Scenario S₁, the implementation of tax exemption scenarios does not generate significant improvement. Across all scenarios, output continues to decline. This suggests that when electricity prices remain high, even fiscal incentives are insufficient to stimulate growth in knowledge-intensive sectors. Electricity sector (Electricity) Across all policy scenarios, output growth in the electricity sector remains at a significantly low level relative to other sectors, with very limited variation across scenarios. This indicates that electricity sector output is largely insensitive to tax exemption policies and is primarily driven by price dynamics rather than fiscal adjustments. Services sector (Serv) Only under Scenario S₁₂ does the services sector record a marginally positive growth rate of 0.13 percent. Since the sector is negatively affected under most other scenarios, this result suggests that capital-related policies play an important role in supporting service-sector expansion and partially offsetting energy price shocks. Overall assessment Overall, the results indicate that fiscal policies such as S₁₁, S₁₂, S₁₃, and S₁₄ function mainly as mitigating instruments rather than substitutes for electricity price reform impacts. Although Scenario S₁₅ performs better than other policy alternatives, it still fails to fundamentally improve the overall economic structure. However, compared to other stabilization policies, it delivers relatively more favorable outcomes and suggests a more promising adjustment path. Analysis of the Effects of Electricity Price Reform Scenarios on Macroeconomic Variables The simulation results indicate that each of the policy scenarios has distinct effects on macroeconomic variables. To elucidate the impacts of these scenarios, the research findings are presented across three time horizons: short-term (2026), medium-term (2038), and long-term (2050). In this analysis, the figures reported in the table represent the percentage change in the respective variable in each of the years 2026, 2038, and 2050, relative to the baseline scenario, as a consequence of implementing the corresponding scenario. Therefore, the changes in sign and magnitude of the coefficients over time should be interpreted as a reflection of the gradual transmission process of the electricity price shock throughout the economy.

Impacts of Electricity Price Reform in Scenario S₁

Scenario S1 provides an appropriate baseline for identifying the transmission path of both direct and indirect impacts of electricity price reform. In the short term, the increase in electricity prices has not yet exerted severe effects on

macroeconomic variables. In this scenario, inflation decreases by 0.57%, while GDP and private consumption increase by 0.60% and 0.39%, respectively. Household welfare also exhibits a 0.39% growth. This outcome can be explained by the time lag inherent in the full transmission of the energy shock to production costs, commodity prices, factor incomes, and decisions regarding consumption and investment. In other words, during the first year of the reform, part of the economy continues to operate based on previous cost structures and existing contracts; consequently, the rise in electricity prices does not necessarily lead to an immediate contraction in economic activity.

Table 4. Macroeconomic Effects of Electricity Price Reform and Compensatory Policies

Variables	Year	S ₁	S ₁₁	S ₁₂	S ₁₃	S ₁₄	S ₁₅
Inflation (%)	2026	-0.57	-0.57	6.01	-0.57	-0.38	5.30
	2038	2.46	2.46	-1.32	2.46	2.33	-2.21
	2050	12.12	12.13	11.98	12.12	12.11	11.51
GDP Growth (%)	2026	0.60	0.60	1.40	0.60	0.63	-0.58
	2038	-17.38	-17.38	-11.73	-17.38	-17.24	-12.96
	2050	-31.72	-31.71	-28.88	-31.71	-31.65	-31.58
Private Consumption (%)	2026	0.39	0.39	2.44	0.39	0.48	2.64
	2038	-6.76	-6.76	-8.72	-6.76	-13.68	-16.96
	2050	-11.83	-11.83	-11.96	-11.83	-19.98	-21.90
Private Household Welfare (%)	2026	0.39	0.39	2.54	0.39	0.45	0.93
	2038	-10.95	-10.95	-13.29	-10.95	-11.00	-14.66
	2050	-18.89	-18.89	-19.11	-18.89	-18.88	-21.33

Source: Research findings

Over time, the effects of the electricity price reform gradually accumulate within the economic structure. In the medium term, inflation in S₁ rises, while both GDP and private consumption decline. Concurrently, household welfare experiences a decrease. This shift from the positive short-term responses to negative medium-term impacts indicates the activation of cost-push and allocative channels resulting from the energy price reform. The increase in electricity costs raises firms' production costs, which are then transmitted to other sectors of the economy through input and commodity prices. Consequently, the erosion of household purchasing power, coupled with reduced aggregate demand and output, exerts a mutually reinforcing downward pressure on the economy.

In the long term, the intensity of these effects amplifies. Inflation rises relative to the previous year, whereas GDP and private consumption continue to decline, and household welfare experiences further contraction. Therefore, the defining characteristic of S₁ is the gradual intensification of the impacts of electricity price reform over time. Essentially, while the electricity price reform generates a relatively limited shock in the short run, its impacts intensify over longer horizons as the shock is more fully integrated into production cost structures, prices, real incomes, and investment decisions. The Role of

Complementary Policies in the Short Run Short-term results indicate that complementary policies trigger divergent responses within the same year as the electricity price reform implementation. Under the capital tax reduction scenario, inflation increases in 2026, whereas GDP, private consumption, and household welfare exhibit growth. Consequently, in the short term, reducing capital taxes serves a dual purpose: it stimulates economic activity, consumption, and welfare, yet simultaneously exerts upward pressure on price levels by boosting aggregate demand and revitalizing economic activity.

This finding is consistent with theoretical expectations. A reduction in capital taxation lowers the user cost of capital and incentivizes investment. The subsequent rise in investment and economic activity can increase aggregate demand in the short run; in contexts where production capacity cannot be expanded rapidly, a portion of this demand surge manifests as inflationary pressure.

Scenario S_{15} also exhibits a distinct short-term behavior. The reduction of taxes on agricultural and industrial output leads to an increase in inflation, private consumption, and household welfare, while GDP declines. This result suggests that supporting production through output tax reductions does not necessarily lead to GDP growth in the first year; due to the time lag between reduced production costs and the supply-side response, the effects may initially manifest through prices and household demand.

In contrast, Scenario S_{14} , characterized by a reduction in taxes on capital demand, results in an increase in GDP, private consumption, and household welfare in the short term, accompanied by a decrease in inflation. Therefore, in the short-term horizon, S_{14} achieves a more balanced combination of growth and price stability compared to S_{12} . However, it should be noted that this superiority is not sustained over longer time horizons.

Shifting Policy Trajectories in the Medium Term By 2038, nearly all scenarios enter a phase where the adverse impacts of electricity price reform on economic activity become more pronounced. In scenarios S_{11} and S_{13} , the results are identical to those of S_1 . This implies that, within the current model framework, reducing labor income taxes and labor demand taxes fails to alter the transmission path of the electricity price reform in the medium term. In both scenarios, GDP declines by 17.38%, private consumption by 6.76%, and household welfare by 10.95%, while inflation increases by 2.46%.

These findings suggest that reducing labor-related taxes possesses limited capacity to offset the long-term effects of the electricity price shock, at least under the model's underlying assumptions. In other words, the reduction in labor costs alone has not been sufficient to compensate for the erosion of household purchasing power and the rise in energy costs to a degree that would alter the trajectory of production and welfare.

In contrast, S_{12} exhibits a distinct performance in the medium term. The reduction in inflation, from 2.46% in S_1 to -1.32% in S_{12} , indicates that the

reduction in capital taxation, over time, has been able to mitigate the price pressures induced by the electricity price reform through the channels of increased production capacity and investment. Furthermore, the contraction in GDP in S_{12} is limited to 11.73%, representing a less severe decline in output compared to S_1 . However, private consumption and household welfare in this scenario decline by 8.72% and 13.29%, respectively, suggesting that the benefits derived from stimulating investment are not necessarily transmitted to households in equal proportion during the medium term.

Scenario S_{14} also shows a relatively weak impact in the medium term. GDP in this scenario decreases by 17.24%, which is only marginally better than S_1 . Concurrently, private consumption and household welfare decline by 13.68% and 11%, respectively. Thus, the reduction in capital demand taxes has failed to generate a significant impact on production in the medium term, while simultaneously exerting considerable pressure on private consumption.

In this time horizon, S_{15} is characterized by a 12.96% decline in GDP, which, compared to S_1 , represents a 4.42 percentage point mitigation in the output contraction. Nevertheless, private consumption and household welfare decrease by 16.96% and 14.66%, respectively. Therefore, while the output tax reduction policy has succeeded in partially alleviating the contractionary effects of the electricity price reform on production, the improvement in output does not automatically translate into improved household welfare.

Intensification of Effects in the Long Term

The results for 2050 are considerably more important for assessing the sustainability of the electricity price reform policy. Under S_1 , inflation increases relative to the previous year, while GDP and private consumption decline, accompanied by a reduction in household welfare. These figures indicate that, in the absence of complementary policies, the cumulative effects of electricity price reform may lead to a substantial contraction in economic activity and welfare over the long term.

S_{12} continues to perform best in terms of GDP over this time horizon. In this scenario, GDP declines by 28.88% in 2050, which, compared with S_1 , represents a 2.84 percentage-point reduction in the magnitude of the output contraction. Inflation in S_{12} reaches 11.98%, slightly below the 12.12% recorded under S_1 . Nevertheless, private consumption and household welfare decline by 11.96% and 19.11%, respectively. Thus, in the long term, a reduction in capital taxation should be regarded less as a direct policy for supporting household consumption and more as a policy aimed at preserving productive capacity and mitigating contractionary pressures on the supply side of the economy.

S_{15} also limits the decline in GDP to 31.58% in the long term, representing an improvement of only 0.14 percentage points relative to S_1 . Compared with its medium-term performance, this result indicates that the supportive effect of reducing output taxes diminishes over time. At the same time, inflation in S_{15} reaches 11.51%, the lowest level among all scenarios. Therefore, although S_{15}

performs best in the long term in terms of containing inflationary pressures, it records the weakest outcomes among the scenarios examined with respect to private consumption and household welfare, which decline by 21.90% and 21.33%, respectively.

This finding reveals an important policy trade-off: a policy capable of reducing inflationary pressures and production costs is not necessarily the policy that provides the greatest protection for household welfare. Overall, this pattern can be attributed to the time lag in the transmission of the energy shock. At the initial stage, electricity price reform may redirect economic resources toward more productive activities and alter economic behavior by improving price signals. However, over time, higher energy costs become incorporated into firms' cost structures, the prices of goods and services, households' real incomes, and investment decisions. Consequently, the contractionary effects become dominant over the initial effects in the medium and long term.

5.1 Sensitivity Analysis

Sensitivity analysis in Computable General Equilibrium (CGE) models is a vital tool for assessing the structural validity of the model and validating its results, as it demonstrates the stability and robustness of the findings against changes in key parameters. To evaluate the structural validity of the model and ensure the robustness of the research findings, sensitivity analysis was conducted on three key behavioral parameters: the Armington elasticity, the elasticity of substitution between capital and energy, and the elasticity of substitution among non-electricity energy inputs. Accordingly, the values of these parameters were varied at 2 and 0.5 times their baseline levels for the years 2026 and 2038, and their effects on macroeconomic variables, including the inflation rate, gross domestic product (GDP), and private household welfare, were examined. Comparing the results of these parametric variations with the outputs of the main scenario indicates that the direction and overall pattern of effects remain fully consistent with the model's base solution in all cases. This behavioral stability confirms that the obtained results are not dependent on the default calibration values, and that the model possesses high validity for policy analysis. The results of the sensitivity

analysis is presented in Table 5

Table 5. Sensitivity Analysis

ESUBM (Armington CES for regional allocation of imports)						
Variable	Initial Value		2× Initial Value		0.5 × Initial Value	
	2026	2038	2026	2038	2026	2038
Inflation Growth Rate	-0.57	2.47	-0.15	4.13	-1.04	1.35
GDP Growth Rate	0.6	-17.38	0.6	-15.78	0.6	-18.68
Private Household Welfare Growth Rate	0.39	-10.94	0.51	-10.68	0.26	-10.97
ELFKEN (Elasticity of substitution in capital-energy subproduction)						
Inflation Growth Rate	-0.57	2.47	-0.07	3.13	-0.84	3.30
GDP Growth Rate	0.6	-17.38	0.68	-8.44	0.5	-23.43
Private Household Welfare Growth Rate	0.39	-10.94	0.6	-6.74	0.19	-12.86
ELFNELY (Elasticity of substitution in non-electr. en. subproduction)						
Inflation Growth Rate	-0.57	2.47	-0.57	2.46	-0.57	2.47
GDP Growth Rate	0.6	-17.38	0.6	-17.38	0.6	-17.38
Private Household Welfare Growth Rate	0.39	-10.94	0.39	-10.95	0.39	-10.94

Source: Research findings

6. Conclusion and Policy Implications

This study investigates the macroeconomic and sectoral impacts of electricity price reform and evaluates the role of stabilization policies in mitigating its adverse effects. The analysis is conducted using a dynamic computable general equilibrium (DCGE) model. The significance of this issue stems from the fact that electricity price fluctuations, as a key production input, directly influence firm costs, sectoral structural adjustments, household welfare, and substitution patterns between production factors.

(a) To estimate the effects of electricity price reform, Scenario S₁ is designed with a constant annual electricity price growth rate of 18 percent over the entire period. The results indicate that in the short run, the gradual increase in electricity prices leads to a decline in output across all sectors except oil and coal. In the long run, however, significant output growth is observed in agriculture, coal, oil, gas, non-energy-intensive industries, petroleum products, and services, indicating a degree of structural adjustment to the new price environment. Nevertheless, this reallocation does not imply uniform improvement across all sectors, as several modern and energy-intensive activities remain under pressure. In particular, the

electricity sector, energy-intensive industries, iron and steel, and information and communication technology experience the most severe adverse effects.

(b) A comparison of the current findings with previous studies demonstrates that the results of this research align with a significant portion of the economic literature. Numerous studies have emphasized that although energy subsidies are intended to support consumers, they can, in practice, lead to suboptimal resource allocation, energy wastage, increased fiscal burdens on the government, and exacerbated inequality (Eslami Andargoli et al., 2014; Khiabani, 2008; Razmara, 1999). Furthermore, the results of this study are consistent with perspectives that view energy price reform as essential for improving economic efficiency, while simultaneously emphasizing the necessity of designing compensatory packages. From this perspective, the findings suggest that the removal or gradual reform of electricity subsidies, if implemented without complementary policies, could exert significant adverse effects on the economy (Silva et al., 2009; Sun, 2015; Sadeghi, Hassanvand, et al., 2019; Turco, 2023).

(c) In the next step, alongside the electricity price shock defined in Scenario S₁, a set of fiscal stabilization policies is implemented to identify the most effective mechanisms for maintaining economic stability. These include S₁₁ (elimination of labor income tax), S₁₂ (elimination of capital income tax), S₁₃ (elimination of labor demand tax), S₁₄ (elimination of capital demand tax), and S₁₅ (elimination of taxes on agricultural and industrial production). The results indicate that none of the examined tax policies is able to fully offset the negative impacts of electricity price increases. However, some policies, particularly the removal of production taxes in agriculture and industry (S₁₅), perform relatively better and partially mitigate output losses in certain sectors. In contrast, policies based on reducing taxes on income or factor demand have more limited effects. This suggests that compensatory policies must be designed in accordance with the structural characteristics of the economy, and that general fiscal instruments alone cannot fully neutralize the sectoral impacts of electricity price shocks.

(d) The macroeconomic implications of electricity price reform suggest that, irrespective of any complementary tax policy, such reforms induce long-term contractionary effects on GDP, consumption, and welfare. While scenarios S₁₅ and S₁₂ outperform the baseline scenario regarding inflation and GDP, they result in diminished household consumption and welfare. These findings highlight the intricate interplay between pricing mechanisms, tax structures, and household well-being, implying that the choice of a complementary policy necessitates a strategic trade-off between macroeconomic stability and social welfare objectives.

(e) Policy Recommendations

1. Electricity price reform should be implemented alongside a complementary policy. The results for S₁ indicate that, although electricity price reform without a complementary policy has limited effects in the short run, it leads to substantial declines in GDP, private consumption, and household welfare

in the medium and long run. Therefore, electricity price reform should be accompanied by a mechanism for allocating the resulting revenues and mitigating its adverse economic consequences.

2. Policy evaluation should simultaneously account for output, prices, and welfare. None of the scenarios outperforms the others across all the variables examined. S_{12} performs better in mitigating the decline in GDP, while S_{15} is more effective in controlling inflation over the long run; however, both scenarios are associated with considerable reductions in private consumption and household welfare. Accordingly, the selection of a complementary policy should be based on a simultaneous assessment of output, inflation, private consumption, and household welfare, rather than on a single indicator. Moreover, no single complementary instrument can be considered suitable for achieving all policy objectives. Policy selection should instead reflect the intended objective and the transmission channel through which the policy operates.
3. The tax policy applied to agricultural and industrial production (S_{15}) has been relatively more successful in certain sectors and has managed to mitigate, to some extent, the decline in output. This finding indicates that compensatory policies should be designed in accordance with the sectoral structure of the economy. General tax instruments alone cannot be expected to offset the effects of the electricity price shock across all sectors.

(F) Notwithstanding the model's coherent outcomes, several principal limitations characterize this study, necessitating consideration in subsequent research endeavors:

1. Omission of Poverty and Distributional Metrics: The employed model is devoid of a poverty- or welfare-centric analytical approach. As such, intra-household and meso-level income distribution is not explicitly modeled, precluding the computation of metrics like the Gini coefficient. This is a critical omission, given the paramount importance of such indices in evaluating distributional equity during energy price reform initiatives. Consequently, future investigations could augment the current framework by integrating micro-household data to systematically incorporate indicators such as the Gini coefficient and poverty measures.
2. Deterministic Framework and Exogenous Shocks: The model implemented herein adheres to deterministic pathways, precluding the explicit accommodation of stochastic shocks originating from geopolitical disturbances, energy supply chain disruptions, or fiscal shocks consequent to diminished governmental tax receipts. This inherent limitation is particularly pertinent in regions susceptible to geopolitical volatilities, where reductions in tax revenues may attenuate or even invert the ramifications of energy price adjustments via exacerbated fiscal deficits. Accordingly, subsequent research could leverage stochastic general equilibrium (SGE) models to concurrently analyze the long-term implications of electricity price reforms and the effects

of energy supply shocks (precipitated by geopolitical crises) and fiscal shocks (characterized by declining tax revenues, expanding budget deficits, and compensatory financing modalities) on key macroeconomic aggregates and energy markets. This approach would facilitate a more empirically grounded and stochastic assessment of the fiscal sustainability of proposed stabilization policies.

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Conceptualization, all authors; methodology, M. I. and M. B.; validation, S. A. J. E. and M. N.; formal analysis, all authors; resources, M. I. and M. B.; writing—original draft preparation, M. B. and M. N.; writing—review and editing, all authors; supervision, M. B. All authors have read and agreed to the published version of the manuscript.

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Appendices

In general, the objective function and constraints at each production level can be expressed as follows:

$$\text{Min } \sum_i \pi_i Z_i \quad \text{st:} \quad Q = \alpha (\sum_i \vartheta_i Z_i^{\frac{\lambda-1}{\lambda}})^{\frac{\lambda}{\lambda-1}} \quad \lambda = \frac{1}{1+r} \quad \text{A-1}$$

where Z_i , π_i , Q , ϑ_i , λ , α , and r respectively indicate the input i , price of input i , production level, distribution parameters, elasticity of substitution, efficiency parameter, and substitution parameter. Conditional demand functions for input i are determined by solving the optimization problem mentioned above.

Input Demand and Unit Cost Functions

$$Z_i = Q \left(\frac{\vartheta_i C_Q}{\pi_i} \right)^{\lambda} \alpha^{\lambda-1} \quad \text{A-2}$$

In the above relation, C_Q represents the unit cost function and depends on the level of production; therefore, it can be said that the cost function with respect to the level of output is an increasing function and homogeneous of degree one.

$$C_Q = \frac{\sum_i \pi_i Z_i}{Q} = \frac{(\sum_i \vartheta_i^{\lambda} \pi_i^{1-\lambda})^{1/1-\lambda}}{\alpha} \quad \text{A-3}$$

Growth Relationships (Demand and Cost)

In equation (4), the demand function is expressed in linearized form in terms of the growth rates of the relevant variables. The dot notation above each variable denotes its rate of growth (i.e., proportional or logarithmic change).

$$\dot{C}_Q = \sum_i \beta_i \left(\frac{\dot{\vartheta}_i}{r} + \dot{\pi}_i \right) - \dot{\alpha} \quad \beta_i = \frac{\pi_i Z_i}{\sum_j \pi_j Z_j} \quad \text{A-4}$$

$$\dot{Z}_i = \dot{Q} + \lambda (\dot{\vartheta}_i + \dot{C}_Q - \dot{\pi}_i) + (\lambda - 1) \dot{\alpha} \quad \text{A-5}$$

Decomposition of Factors Affecting Input Demand

Input demand is driven by four main components, which can be summarized as follows:

1. Output expansion effect $\dot{Q}$: This effect captures changes in input demand resulting from variations in aggregate output. An increase in production scale leads, ceteris paribus, to a proportional increase in demand for all inputs.
2. Substitution effect $(\lambda(\dot{C}_Q - \dot{\pi}_i))$: This component reflects the response of input demand to changes in relative prices. In general, an increase in the relative price of a given input reduces its demand while increasing the demand for substitute inputs, consistent with standard substitution behavior in production theory.
3. Input-augmenting technological change $(\lambda \dot{\vartheta}_i)$: Improvements in input-specific efficiency have a non-neutral effect on input demand. The magnitude and direction of this effect depend on the elasticity of substitution; higher substitutability among inputs increases the likelihood

that efficiency improvements translate into higher utilization of the corresponding input.

4. Neutral technological change (total factor productivity growth, TFP) $((\lambda - 1)\dot{\alpha})$: This term represents Hicks-neutral technological progress, which affects all inputs proportionally by shifting the overall production technology.

Finally, a consistent mapping can be established between the mathematical relationships defined in equations (1)–(5) and the behavioral equations of firms in the GTAP-E-Power model. This correspondence ensures that the behavioral structure across all production nests is theoretically consistent with the underlying optimization framework. In particular, this equivalence holds across both the aggregate output nest and the value-added–energy composite nest, as summarized in Table 1.

Table A-1. Mapping between theoretical equations and GTAP-E-Power behavioral structure

Variable / Parameter	Top-level output nest (Total output layer)	Variable / Parameter	Value-added–energy nest
$qf_{ijr} = \dot{Z}_i$ $= Q\dot{F}_{ijr}$	Demand for input i for use in sector j in region r (%change)	$qf_{ijr} = \dot{Z}_i$	Demand for input i for use in sector j in region r (%change)
$\pi f_{ijr} = \dot{\pi}_i$ $= \pi\dot{F}_{ijr}$	price of input i by firms in sector j of region r(%change)	$\pi f_{ijr} = \dot{\pi}_i$	price of input i by firms in sector j of region r(%change)
$qo_{jr} = \dot{Q}$ $= Q\dot{O}_{jr}$	quantity of output j in region r(%change)	$af_{ijr} = \frac{\lambda_{jr}}{\lambda_{jr} - 1} \dot{\vartheta}_{ijr}$	biased technical change of input I in sector j in region r (%change)
$\pi s_{jr} = \dot{C}_Q$	Supply price of commodity I in region r(%change)	$qf^{vaen}_{jr} = \dot{Q}$	Demand for Composite of value added and energy
$af_{ijr} = \frac{\lambda}{\lambda - 1} \dot{\vartheta}_{ijr}$ $= -\frac{\dot{\vartheta}_{ijr}}{r}$	biased technical change of input I in sector j in region r (%change)	$\dot{\alpha} = 0$	TFP change is zero in this nest and others
$ao_{jr} = \dot{\alpha}$	Hicks neutral technological change(%change)	$\pi f^{vaen}_{jr} = \dot{C}_Q = \pi\dot{F}^{vaen}_{jr}$	Composite price of value added and energy
$ESIV_{jr} = \lambda_{jr}$	Elasticity of substitution between intermediate and value added	$EVA_{jr} = \lambda_{jr}$	Elasticity of substitution between input in value-added and energy nest

Linear and Nonlinear Forms of Conditional Demand Functions

In different production technology nests, conditional demand functions (in both linearized and nonlinear forms) are derived along with composite price indices. Based on the cost-minimization principle in the top-level output nest, the composite demand for the value-added–energy bundle and intermediate inputs is obtained as follows. It should be noted that equations (7) and (8) represent the linearized forms of equation (6).

1-Top-Level Output Nest

$$QF_{ijr} = QO_{jr}AO_{ir}^{ESIV_{jr}-1} \left(\frac{\pi F_{ijr}}{\vartheta_{ijr}\pi S_{jr}} \right)^{-ESIV_{jr}} \quad A-6$$

$$qf_{ijr} = qo_{jr} + ESIV_{jr}(\vartheta_{ijr} + \pi s_{jr} - \pi f_{ijr}) + (ESIV_{jr} - 1)ao_{jr} \quad A-7$$

$$qf_{ijr} = qo_{jr} - ao_{jr} - af_{ijr} + ESIV_{jr}(ao_{jr} + af_{ijr} + \pi s_{jr} - \pi f_{ijr}) \quad A-8$$

Value-Added–Energy Nest

At the second level of the production structure, the demand for primary factors and the capital–energy composite is determined. In the GTAP-E-Power framework, energy inputs are allocated within the value-added nest to allow for substitution between capital and energy. In this context, $QF_{vaen"jr}$ and $\pi F_{vaen"jr}$ represent, respectively, the demand for and the price of the value-added–energy composite.

$$QF_{ijr} = QF_{vaen"jr} \left(\frac{\pi F_{ijr}}{\vartheta_{ijr}\pi F_{vaen"jr}} \right)^{-ESVA_{jr}} \quad A-9$$

$$qf_{ijr} = qf_{vaen"jr} - af_{ijr} + ESVA_{jr}(\vartheta_{ijr} + \pi f_{vaen"jr} - \pi f_{ijr}) \quad A-10$$

$$qf_{ijr} = qf_{vaen"jr} + ESVA_{jr}(\pi f_{vaen"jr} + af_{ijr} - \pi f_{ijr}) \quad A-11$$

Composite Price Indices and Cost Decomposition

The composite price of the value-added–energy bundle (in percentage change form), as specified in Equation (12), is defined as a weighted average of the prices of primary production factors and the capital–energy composite.

$$\pi f_{vaen"jr} = \sum_{i=VAEN} SHVAEN_{ijr} \times [\pi f_{ijr} - af_{ijr}] \quad A-12$$

Equation (13) represents the percentage change in the output supply price, which is defined as a cost-share weighted average of all input prices, including intermediate inputs and the primary factor composite.

$$\pi s_{jr} = -ao_{jr} + \sum_{i=OUT_COMM} SHTC_{ijr} \times [\pi f_{ijr} - af_{ijr}] \quad A-13$$

In these equations, $SHVAEN_{ijr}$ denotes the cost share of each input within the corresponding production nest, while $SHTC_{ijr}$ represents the share of input (i) in

the total production cost of sector (j). According to Equation (13), an improvement in the productivity of input (i) or an increase in total factor productivity (TFP) leads to a reduction in the output supply price.

Intermediate Input Nest

At this level, the demand for domestic intermediate inputs QFD_{ijr} and imported intermediate inputs QFM_{ijr} is determined as a composite of these two input categories. Changes in the composite price of intermediate inputs πft_{ijr} are defined as a cost-share weighted average of domestic πfd_{ijr} and imported πfm_{ijr} input prices.

The parameter $SHRM_{ijr}$ denotes the cost share of imported input (i) in sector (j) and region (r). The $ESARM_{jr}$ parameter represents the Armington elasticity of substitution, which governs the degree of substitutability between domestic and imported goods. An increase in this elasticity leads to a stronger substitution effect and therefore amplifies import demand responses to relative price changes.

$$QFD_{ijr} = QFT_{ijr} \left(\frac{\pi FD_{ijr}}{\vartheta_{ijr} \pi FT_{ijr}} \right)^{-ESARM_{jr}} \quad A-14$$

$$qfd_{ijr} = qft_{ijr} + ESARM_{jr} (\pi ft_{ijr} - \pi fi_{jr}) \quad A-15$$

$$QFM_{ijr} = QFT_{ijr} \left(\frac{\pi FM_{ijr}}{\vartheta_{ijr} \pi FT_{ijr}} \right)^{-ESARM_{jr}} \quad A-16$$

$$qfm_{ijr} = qft_{ijr} + ESARM_{jr} (\pi ft_{ijr} - \pi fm_{ijr}) \quad A-17$$

$$\pi ft_{ijr} = SHRM_{ijr} \times \pi fm_{ijr} + (1 - SHRM_{ijr}) \times \pi fd_{ijr} \quad A-18$$

Capital–Energy Composite Nest

At this level, the optimal demand for capital and the energy composite is determined by relative prices and input-specific technological changes. πF_{eny}^{jr} and QF_{eny}^{jr} represent, respectively, the price and quantity of the capital–energy composite.

The composite price is defined as a cost-share weighted average of the prices of capital and energy. An improvement in energy efficiency qf_{eny}^{jr} reduces the price of the energy bundle, as indicated by Equations (21) and (24). Through the substitution effect, this decline in the composite energy price increases energy demand. In addition, these changes directly affect energy demand as specified in Equations (19), (20), (22), and (23).

$$i \in \{capital, energy\} \quad QF_{ijr} = QF_{ken}^{jr} \left(\frac{\pi F_{ijr}}{\vartheta_{ijr} \pi F_{ken}^{jr}} \right)^{-ESCE_{jr}} \quad A-19$$

$$qf_{ijr} = qf_{ken"jr} - af_{ijr} + ESCE_{jr}(\pi f_{ken"jr} + af_{ijr} - \pi f_{ijr}) \quad A-22$$

$$\pi f_{ken"jr} = \sum_{i \in KEN} SHKEN_{ijr} \times (\pi f_{ijr} - af_{ijr}) \quad A-23$$

5- Energy Nest

At this level, demand for the electricity and non-electricity energy composite is derived from Equations (22) and (23), while the composite energy price is obtained from Equation (24). The parameter $SHENY_{ijr}$ denotes the cost share of electricity and non-electricity energy inputs within the energy nest.

$$i \in \{electricity, non - QF_{ijr} = QF_{eny"jr} \left(\frac{\pi F_{ijr}}{\partial_{ijr} PF_{eny"jr}} \right)^{-ESEIT_{jr}} - electricity(nely)\} \quad A-22$$

$$qf_{ijr} = qf_{eny"jr} - af_{ijr} + ESEIT_{jr}(\pi f_{eny"jr} + af_{ijr} - \pi f_{ijr}) \quad A-23$$

$$\pi f_{eny"jr} = \sum_{i \in ENY} SHENY_{ijr} \times (\pi f_{ijr} - af_{ijr}) \quad A-24$$

Non-Electricity Nest

At this level, the composite demand for coal and non-coal energy inputs is derived as a function of relative energy prices (Equations 25 and 26). In addition, the composite price of non-electricity energy $\pi f_{nely"jr}$ is defined as a cost-share weighted average of coal and non-coal energy prices. The parameter $SHNELY_{ijr}$ represents the cost share of each energy input within this nest.

$$QF_{ijr} = QF_{nely"jr} \left(\frac{\pi F_{ijr}}{\partial_{ijr} \pi F_{nely"jr}} \right)^{-ESNL_{jr}} \quad i \in \{\text{coal, non - coal(ncol)}\} \quad A-25$$

$$qf_{ijr} = qf_{nely"jr} - af_{ijr} + ESNL_{jr}(\pi f_{nely"jr} + af_{ijr} - \pi f_{ijr}) \quad A-26$$

$$\pi f_{nely"jr} = \sum_{i \in NELY} SHNELY_{ijr} \times (\pi f_{ijr} - af_{ijr}) \quad A-27$$

Non-Coal Energy Nest

Oil, natural gas, and petroleum products constitute the three energy inputs other than coal. Equations (28) and (29) describe the optimal demand for these inputs. The composite price of these energy carriers is determined by Equation (30). The elasticity of substitution among these inputs $ESNC_{jr}$ plays a crucial role in determining demand responses; a higher substitution elasticity implies that changes in relative prices have a stronger impact on input demand.

$$QF_{ijr} = QF_{ncoal"jr} \left(\frac{\pi F_{ijr}}{\partial_{ijr} \pi F_{ncoal"jr}} \right)^{-ESNC_{jr}} \quad i \in \{\text{oil, gas, oil products}\} \quad A-28$$

$$qf_{ijr} = qf_{ncoal"jr} - af_{ijr} + ESNC_{jr}(\pi f_{ncoal"jr} + af_{ijr} - \pi f_{ijr}) \quad A-29$$

$$\pi f_{ncoal"jr} = \sum_{i \in NCOAL} SHNCOAL_{ijr} \times (\pi f_{ijr} - af_{ijr}) \quad A-30$$

8-Base-Load and Peak-Load Layer

Base-load and peak-load electricity demand are assumed to be substitutable through a Constant Elasticity of Substitution (CES) function with a substitution elasticity of $ESBP_{jr}$. The cost-minimization problem yields the demand functions presented in Equations (31) and (32), while the corresponding base-load and peak-load price index is given by Equation (33).

$$QF_{ijr} = QF_{egen"jr} \left(\frac{\pi F_{ijr}}{\vartheta_{ijr} \pi F_{egen"jr}} \right)^{-ESBP_{jr}} \quad i \in \{peak\ load, base\ load\} \quad A-31$$

$$qf_{ijr} = qf_{egen"jr} - af_{ijr} + ESBP_{jr} (\pi f_{egen"jr} + af_{ijr} - \pi f_{ijr}) \quad A-32$$

$$\pi f_{egen"jr} = \sum_{i \in EGEN} SHBP_{ijr} \times (\pi f_{ijr} - af_{ijr}) \quad A-33$$

Peak-Load Layer

The substitution among peak-load generation technologies is modeled using a CES function with a substitution elasticity of $ESPK_{jr}$, which represents the elasticity of substitution between fossil-fuel-based and renewable energy technologies. The price of the peak-load composite is determined according to Equation (36) and is measured using the share parameter $SHPKL_{ijr}$.

$$QF_{ijr} = QF_{peak"jr} \left(\frac{\pi F_{ijr}}{\vartheta_{ijr} \pi F_{peak"jr}} \right)^{-ESPK_{jr}} \quad i \in \{fossil\ fuel, renewables\} \quad A-34$$

$$qf_{ijr} = qf_{peak"jr} - af_{ijr} + ESPK_{jr} (\pi f_{peak"jr} + af_{ijr} - \pi f_{ijr}) \quad A-35$$

$$\pi f_{peak"jr} = \sum_{i \in PEAK} SHPKL_{ijr} \times (\pi f_{ijr} - af_{ijr}) \quad A-36$$

10-Base-Load Layer

Finally, at the lowest level of the technology nesting structure, base-load electricity demand is derived from a CES function with a substitution elasticity of $ESBAS_{jr}$, as specified in Equations (37) and (38). The corresponding price index represents the weighted average price of energy inputs within the base-load layer, where the weighting factor $\pi f_{base"jr}$ denotes the cost share of each energy input in this layer.

$$QF_{ijr} = QF_{base"jr} \left(\frac{\pi F_{ijr}}{\vartheta_{ijr} \pi F_{base"jr}} \right)^{-ESBAS_{jr}} \quad i \in \{fossil\ fuel, renewables\} \quad A-37$$

$$qf_{ijr} = qf_{base"jr} - af_{ijr} + ESBAS_{jr} (\pi f_{base"jr} + af_{ijr} - \pi f_{ijr}) \quad A-38$$

$$\pi f_{base"jr} = \sum_{i \in BASE} SHBSL_{ijr} \times (\pi f_{ijr} - af_{ijr}) \quad A-39$$

Dynamic Block

Time and Capital Accumulation

To conduct realistic and comprehensive long-run dynamic analyses, it is necessary to move beyond the limitations of the standard GTAP framework regarding interregional capital mobility and explicitly incorporate international capital flows through an extension of the national accounts structure. Within a dynamic framework, time is treated as a continuous variable in order to realistically capture international capital mobility and its effects on regional capital stocks and investment. The evolution of the capital stock over time is described by Equation (40):

$$CS_i = CS_{i0} + \int_{T_0}^T I_i(t) dt \quad A-40$$

where t denotes the length of the time interval. Totally differentiating the above equation yields Equation (41):

$$CS_i \cdot \frac{cs_i}{100} = I_i \cdot t \quad A-41$$

Furthermore, Equation (3) can be reformulated as follows:

$$VCS_i \cdot cs_i = 100 VI_i \cdot t \quad A-42$$

In these expressions, CS_{i0} and VCS_i denote, respectively, the capital stock in the base year T_0 and the monetary value of the capital stock in region i . Furthermore, I_i represents net investment, VI_i the monetary value of net investment, cs_i the percentage change in the capital stock of region i , and t the percentage change in time. Within the framework of a comparative-static simulation, the percentage change in the capital stock is assumed to be zero. By introducing a region-generic shift parameter, $SCSWO$, and a region-specific shift parameter, SCS_i , Equation (4) and the differential equation (5) are obtained as follows:

$$CS_i = SCSWO \cdot SCS_i \cdot \left[CS_{i0} + \int_{T_0}^T I_i dT \right] \quad A-43$$

$$VCS_i \cdot cs_i = VCS_i [scswo + scs_i] + 100 VI_i \cdot t \quad A-44$$

Financial Assets and Capital Ownership

To enable the modeling of international capital mobility, financial assets are introduced into the model in order to establish an explicit distinction between the location of assets and their ownership. Within this framework, regional households (RH) and firms (F) differ with respect to capital ownership. Firms own physical capital, whereas households hold financial assets and are also the owners of land and natural resources. Consequently, these assets represent indirect ownership claims on productive capital as well.

The value of firm ownership in region i , denoted by WQF_i is equal to the value of the capital stock, VCS_i , which is obtained as the product of the price of capital goods, PCG_i , and the capital stock, CS_i , in region i . Accordingly, the corresponding differential equation, Equation (6), is derived as follows:

$$wqf_i = pcg_i + cs_i \quad A-45$$

where lowercase notation denotes percentage changes. The variable pqf_i represents the percentage change in the share price of firms in region i . Accordingly, the following relationship is obtained:

$$pqf_i = pcg_i$$

A-46

Regional households exclusively hold domestic firm equities as well as shares in the global fund (GT). The equity holdings of each region in the global fund are treated as that region's foreign assets. Accordingly, total regional household wealth ($WQRH_i$) is expressed as follows:

$$WQRH_i = PCG_i \int_{T_0}^T QQRHF_i dT + PQGT \int_{T_0}^T QQRHGT_i dT \quad A-47$$

where:

$QQRHF_i$: denotes the number of domestic firm shares purchased by households;

$QQRHGT_i$: denotes the number of regional household shares in the global fund;

and $PQGT$: represents the price of shares in the global fund.

By totally differentiating the above expression and substituting Equation (7),

Equation (9) is obtained as follows:

$$WQRH_i \cdot wqrh_i = WQRHF_i \cdot pcg_i + WQRHGT_i \cdot pqgt + 100(VQRHF_i + VQRHGT_i) \cdot t \quad A-48$$

where $WQRHF_i$ and $WQRHGT_i$ denote, respectively, the wealth of regional households held in the form of domestic firm equity and holdings in the global fund. Similarly, $VQRHF_i$ and $VQRHGT_i$ represent the value of new investment by regional households in domestic firms and in the global fund in region iii, respectively.