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Economic and Distributional Impacts of Selected Carbon Pricing Policies for the Arab Republic of Egypt

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Abstract

The Arab Republic of Egypt is the 24th largest carbon dioxide emitter from fossil fuel combustion in the world and the third largest emitter in the Middle East and North Africa region after the Islamic Republic of Iran and Saudi Arabia. Egypt has set a target of reducing one-third of its national greenhouse gas emissions under the Paris Climate Agreement. Pricing instruments, such as the removal of existing fossil fuel subsidies and the introduction of a carbon tax, help the country to achieve its emission reduction targets. However, the economic, social, and environmental impacts of such policies are unknown. This study develops a computable general equilibrium model for Egypt to investigate the economic, distributional, and climate change mitigation effects of fossil fuel subsidy removal and introduction of a carbon tax under alternative schemes to recycle the saved subsidies and carbon tax revenues. Four revenue recycling schemes are considered: public debt reduction, equal or progressive cash transfers to households, and cutting corporate income taxes. The numerical results indicate that removing existing petroleum subsidies and introducing of a carbon tax of LE 600 per ton of carbon dioxide would reduce national carbon dioxide emissions by up to 11 percent without significantly affecting the economy. When the saved subsidies and carbon tax revenues are given back to households through cash transfers, the income of poorer households would rise relative to that of richer households, ensuring that this revenue recycling scheme is progressive. The policies affect commodity prices and sectoral output not only in different magnitudes, but also in different directions across the revenue recycling schemes.

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1. Introduction

The Arab Republic of Egypt is the 24th largest CO_2 emitter from fossil fuel combustion in the world and the third largest emitter in the MENA region after the Islamic Republic of Iran (7th largest) and Saudi Arabia (11th largest) (World Bank, 2022a). Total greenhouse gas (GHG) emissions in 2019 were 1.6 times as high as in 1990; and per capita emissions increased by 47% during over 1990–2019 (World Bank, 2022b). The country is highly vulnerable to climate change due to increased water scarcity, loss of biodiversity and food insecurity (World Bank, 2022). Considering the growth of GHG emissions, its vulnerability to climate change,[2] and realizing the global responsibility to address climate change, Egypt has actively participated in international efforts to combat climate change. Egypt ratified the United Nations Framework Convention on Climate Change (UNFCCC) in 1994. Under the Paris Climate Agreement, Egypt has set a target of reducing one-third (33%) of its emissions in the baseline in 2030 (Government of Egypt, 2022). As indicated in its Nationally Determined Contribution (NDC), the emission mitigation target will be achieved through various measures, such as removing fossil fuel subsidies, promoting renewable energy, improving energy efficiency, and transitioning to low-carbon transportation. Egypt's commitment to contribute to global efforts to address climate change is also reflected in its hosting of the 27th Conference of the Parties (COP) to the UNFCCC in November 2022. Despite Egypt's target of reducing 33% of its GHG emissions as specified in its NDC, an acute knowledge gap exists on how meeting the NDC target will affect the overall economy and how these impacts will be distributed across households.

Carbon pricing instruments, such as a carbon tax, are the main pricing instruments considered by many countries to reduce their GHG emissions because they are economically

[2] According to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), the Nile Delta is one of the three extreme vulnerable hotspots mega-deltas directly affected by 2050 (Nicholls et al. 2007). The timing and volume of Nile River water availability to Egypt is increasingly uncertain due to climate change impacts (World Bank, 2022b).

efficient (see e.g., Aldy et al. 2010; Timilsina, 2022; Timilsina et al. 2022). At present, more than 75 economies (regional, national and sub-national) have already introduced carbon pricing instruments – carbon tax or emission trading scheme (ETS) or both (World Bank, 2023). More than 100 countries, including developing countries, have considered carbon pricing as one of the policy options to achieve their NDC targets (World Bank, 2023).

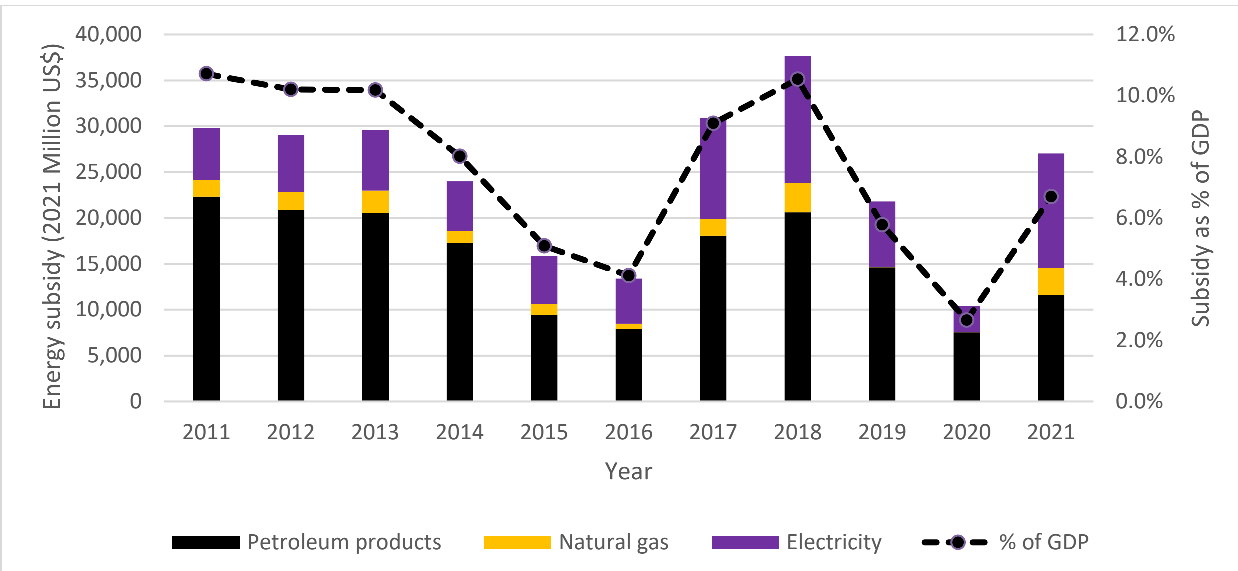
A large number of studies have been carried out on the economic and distributional implications of carbon pricing in both developed and developing economies.[3] For example, Timilsina et al. (2022) investigates the impacts of a carbon tax to meet the NDC in China considering nine schemes for utilizing the carbon tax revenues. It finds that a pricing instrument, carbon tax with tax revenue recycled as an output rebate to export-intensive non-energy industries, would cause nine times less GDP loss as compared to a command-and-control policy to meet the NDC target. In a study for Côte d'Ivoire, Timilsina et al. (2021) show that the impacts of a carbon tax depend on how the carbon tax revenue is used in the economy. Under certain revenue recycling schemes (e.g., cutting existing labor tax in formal firms), a carbon tax could increase GDP. Usually, a carbon tax is regressive, as reported by many existing studies included in the review study by Timilsina (2022). This is because the share of energy expenditure in the total household expenditure is normally higher in low-income households than in high-income households (Williams et al., 2015; Jiang et al., 2015). A carbon tax, therefore, faces political reluctance and social resistance. However, a carbon tax can be made progressive through a targeted transfer of carbon tax revenues to low-income households (Timilsina and Sebsibie, 2023). The proposed study will also refer to existing studies, such as Rausch et al. (2011) and Steckel et al. (2021) for the distributional analysis.

The use of fossil fuels is the primary source of GHG emissions in Egypt. While the consumption of fossil fuels, particularly petroleum products and natural gas, is subsidized to lower the energy expenditures of households and production sectors, it causes increased use of fossil fuels and thereby associated GHG emissions. Removals or reductions of fossil fuel subsidies not only lower the fuel subsidy burden of the government, but also help reduce GHG emissions. The fossil fuel subsidy is one of the major expenditures of the Government in Egypt, which was

[3] Please see Timilsina (2022) for in-depth review of carbon tax studies conducted over the last three decades.

equivalent to 5.3% of GDP, on average, over the last decade (Figure 1).[4] The Government of Egypt (GOE) started reforming fossil fuel subsidies in 2012 by increasing the prices of liquefied petroleum gas (LPG), gasoline, natural gas, and diesel. It dropped to less than 2.6% in 2016, increasing to more than 6.7% in 2018.[5] Therefore, it is important to understand the environmental impacts of fossil fuel subsidy removals in addition to the economic impacts.

Figure 1. Fuel subsidies in Egypt (2021 Million US$) and the ratio of fuel subsidies to GDP (%)



Source: IEA (2022) and World Bank (2023)

It is possible to introduce a carbon tax in an economy where fossil fuel subsidies still exist because the distributional implications of a carbon tax and the removal/reduction of fossil fuel subsidies fall differently on economic agents (households, producers). A carbon tax falls mostly on emission-intensive fuels (e.g., coal) and heavy petroleum products (fuel oil) which are mainly used for power generation and industrial applications. Removal of fossil fuel subsidies impacts fuels that are mainly used by households for cooking and home heating. However, introducing a carbon tax without removing fossil fuel subsidies gets criticism because both policies cause an

[4] If the electricity subsidy is also included, the total energy subsidy accounts for, on average, 7.6% of the GDP during the same period.

[5] The change in subsidy after 2016 is mostly influenced by the exchange rate. The US$ value of 100 EGP was 10 in 2016, it decreased by 44% to 5.6 in 2018, and increased to 6.4 in 2021.

increase in end-use prices of fossil fuels, thereby reducing their demand and associated emissions. Therefore, it would be more appropriate to eliminate subsidies to fossil fuels before imposing a carbon tax on them. Moreover, it would be interesting to compare the economy-wide impacts of a carbon tax and the removal of fossil fuel subsidies so that policy makers can make better decisions if they have to choose one of them.

A few studies have been done on the economic impacts of fossil fuel subsidy removal in Egypt.[6] For example, Breisinger et al. (2019) assess the macroeconomic impacts of phasing out energy subsidies in Egypt under alternative scenarios using a CGE model. They find that the removal of energy subsidies would have negative impacts on the economy (GDP loss) and household welfare in the short term. In an earlier study using the CGE approach, Abouleinein et al. (2009) show that a gradual removal of fuel subsidies over a five-year period would result in slower economic growth than that in the reference case (i.e., without subsidy removal). However, using saved subsidies for cash transfers to low-income households in both rural and urban areas would have superior growth and distributional impacts than the alternative where the government uses the saved subsidies as in the reference case. Using a CGE model, Elshennawy (2014) reports that phasing out energy subsidies would cause welfare loss irrespective of the speed of subsidy reduction (i.e., instantaneously or gradually). Eldeep and Zaki (2023), on the other hand, find that immediate cut of petroleum subsidies and allocating the savings to finance capital expenditure (i.e., public investment in infrastructure and human capital) would lead to long-run positive impacts on real GDP, although it will have negative economic impacts in the short-run. Glomm and Jung (2014) also find that removal of fuel subsidies could increase GDP if the saved subsidy is used for infrastructure investment. On the other hand, if the saved subsidy is recycled to households through a lump-sum rebate, there would be a loss in GDP. Using an Input-Output (I-O) model, Cockburn et al. (2014) find that the adverse impacts of increased fuel prices resulting from the removal of fuel subsidies fall on children's living conditions, negatively affecting their physical and intellectual development. In summary, existing literature converges that removing fuel subsidies may not benefit the Egyptian economy with some exceptional cases of utilization of the saved subsidy (i.e., using the saved subsidies for infrastructure investment). The results are

[6] Timilsina and Pargal (2020) present a brief review of studies analyzing macroeconomic impacts of energy subsidy reforms in different countries including Egypt.

highly sensitive to the economic structure of an economy. Since Egypt is an energy-exporting country, these results might hold across studies. However, such results do not hold in other countries, particularly energy-importing countries. For example, in the case of Bangladesh, Timilsina and Pargal (2020) find economic gains through the removal of fuel subsidies.

On the economic impacts of a carbon tax in Egypt, Elshennawy and Willenbockel (2021) find, using a CGE model, that the impacts depend on the schemes to recycle the tax revenue. If the tax revenue is used to reduce other tax rates, the carbon tax would have a positive impact on economic activity. On the other hand, if the tax revenue is used by the government or cash is transferred to households, it would cause a GDP loss. This finding is consistent with many other carbon tax studies reviewed by Timilsina (2022).

While there are a few studies for Egypt, as discussed above, either on the removal of fuel subsidies or carbon taxes, no study exists that analyzes the economic and distributional impacts of simultaneous implementation of both policies (i.e., carbon tax and removal of fossil fuel subsidies). It would also be important to understand how differently these policies affect different groups of households by income and production sectors. Would the removal of fossil fuel subsidies and carbon tax that have a similar range of economic impacts also have similar impacts on CO_2 emissions? How would the impacts of these policies vary across alternative scenarios for the use of saved subsidies and carbon tax revenues? This study aims to answer these questions using a computable general equilibrium (CGE) model for the Egyptian economy. The findings of the study are expected to offer some guidance to policy makers on the selection of pricing policy instruments (e.g., carbon tax or fossil fuel subsidy removal or both) to reduce CO_2 emissions from the Egyptian economy.

The paper is organized as follows. Section 2 briefly describes the CGE model developed, followed by a discussion on the data used. Section 3 presents the scenarios for policy simulation. Section 4 provides the macroeconomic and sectoral effects of the simulated policies and discusses their distributional impacts. Finally, section 5 draws key conclusions and policy implications.

2. Methodology

2.1 Model

The study will develop a structural model in a computable general equilibrium (CGE) setting. Egypt has a long history of using CGE models to help policy makers on key economic and sectoral policies. Lofgren (1994) critically reviews CGE models developed for Egypt since the early 1970s. More recently, this modeling approach has been used by various studies, such as Eldeep and Zaki (2023) for analyzing the impacts of economic reforms[7] Egypt is implementing to stabilize its economy; Eldeep and Zaki (2022) for analyzing the impacts of COVID vulnerability and policy response; Haddad et al. (2016) for analyzing the impact of transportation infrastructure policies; Helmy et al. (2019) for assessing the impacts of cash transfers to households; Elshennawy (2014) for analyzing the removal of fossil fuel subsidies; and Elshennawy et al. (2016) for analyzing the impacts of climate change adaptation measures. Breisinger et al. (2019) develop a CGE model to analyze the economic effects of energy subsidy removal in Egypt. However, studies using CGE models for analyzing climate change mitigation policies, particularly carbon pricing for Egypt, are rare. This study develops a CGE model by explicitly representing all fossil fuel and fossil-fuel-intensive sectors (e.g., power generation, transportation, carbon-intensive manufacturing). The basic structure of the model is similar to Timilsina and Sesibie (2023). A brief description of the model is provided below, while the details of the model are presented in Appendix A.

The CGE model developed here is a multi-sector, multi-household model. It is static (single period) in nature. A static model considers an economic equilibrium for the single period (e.g., one year or longer than a year without significant change in the structure of economies). The selection of a static approach is based on the objective of a study, which is to compare alternative designs for both policies (i.e., fossil fuel subsidy removal and introduction of a carbon tax) -- a comparison of situations with and without fuel subsidy in a given year or a comparison of revenue recycling schemes for a given carbon tax. It models the behavior of four economic agents: household, government, enterprise, and the rest of the world (ROW). Production sectors are classified into 19

[7] The programs simulated in the study are (i) imposition of VAT, (ii) elimination of petroleum subsidies, (iii) devaluation of the Egyptian pound, and (iv) structural reforms, including gradual tariff liberalization on all commodities, reallocating public expenditure to investment in education and health.

sectors, as shown in Table 1. The electricity sector is one of them.[8] The production behavior of each sector is represented through a nested constant elasticity of substitution (CES) functional form. The nested structure of production is presented in Figure 2. The nested CES structure has four tiers of nesting. The top level of nesting aggregates production factors (value added) and intermediate inputs using a constant elasticity of substitution (CES) functional form. The middle level has two sides: aggregate labor and capital to form value added on the left-hand side and aggregation of energy and non-energy goods on the right-hand side. In the third tier, non-energy intermediate consumption is aggregated using a Leontief functional form[9] on the left-hand side, and electricity and fossil fuels are combined using a CES function on the right-hand side. At the next tier on the same side, coal and petroleum (a CES combination petroleum products and natural gas) bottom tier are aggregated using a CES production function. At the very bottom tier in the right-hand side, petroleum products and natural gas are combined using a CES function. This type of nested structure is common in most CGE models (see, for example, Goulder, 1995; Gurgel et al. (2019); Timilsina et al., 2021).

Table 1. Definition of sectors and commodities

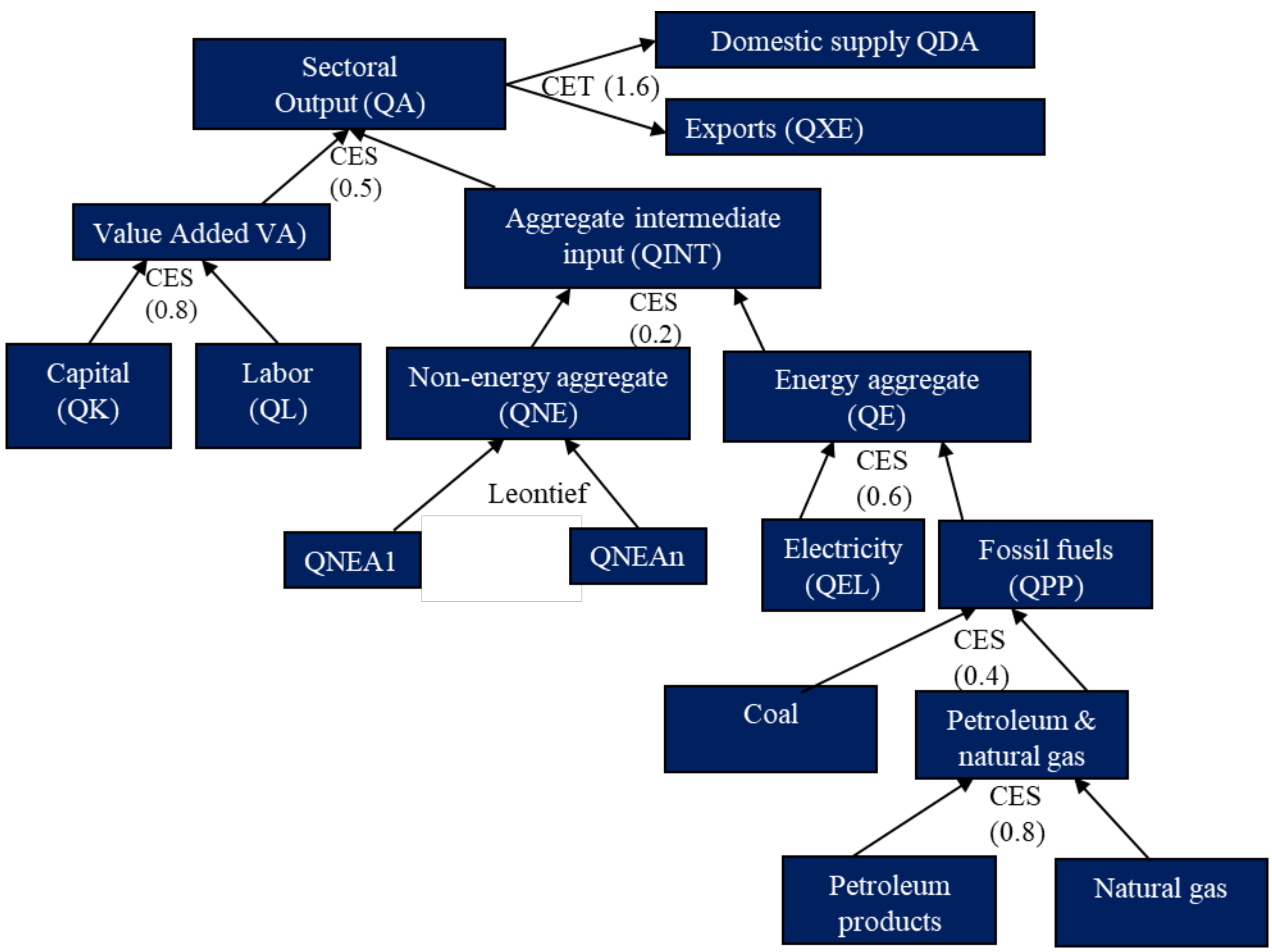
Sector/commodity name	Inclusion of activities
Agriculture & forestry	Crops, vegetables, fruits, livestock, fishery, forestry
Crude oil	Crude oil production
Natural Gas	Natural gas production and processing
Other mining	All mining except energy mining
Food, beverage, tobacco	Processed food, beverages, tobacco
Textile	Textile, apparel, leather
Petroleum products	Refined petroleum products
Chemicals	Chemicals, fertilizers,
Non-metals	All non-metallic mineral products
Metals	All primary metals and their intermediate products
Machinery	Machinery, all types of equipment, vehicles
Other manufacturing	Wood and products, pulp & paper, and every other manufacturing not covered by manufacturing sectors listed here
Electricity	All type of electricity generation, transmission and distribution
Construction	All construction related activities

[8] In some CGE models, particularly those focusing on climate policy analysis, the electricity sector is disaggregated by generation technologies (e.g., hydro, coal, gas). We have not done so because of a lack of data.

[9] The Leontief functional form is selected because elasticities of substitution between the non-energy sectors are not available.

Trade	Wholesale and retail trade
Transport	Public transportation services
Commercial services	All types of commercial services
Public services	Public services (education, healthcare, public administration, water supply)
Other services	All other remaining services

Figure 2: Production structure in the model



Note: The values in the parenthesis are elasticities of substitution.

Households are first divided into five groups by income (quantile). A representative (or average) household from each quantile is modeled using a Cobb-Douglas functional form. Each household group supplies labor to the production sector. Households' income includes salary and wage, income from capital rents, and transfer payments from the government and the rest of the world. Households pay taxes from this total income, and the remaining income (i.e., disposable income) is allocated for consumption, transfers to other economic agents, and savings. The consumption/saving allocation is based on the marginal propensity of consumption, which is based on the data from the social accounting matrix (SAM) used for this study.

The total government revenues are generated through personal and corporate income taxes, excise taxes, import duties, and transfers from other economic agents (i.e., households, enterprises, and the rest of the world).[10] It is allocated for public expenditures, transfers to other agents, and public savings. Public expenditure accounts for government spending on wage and salary of government employees, expenditure and defense, healthcare and education. Since these are the essential services and required to be maintained by the government, the total government expenditure is fixed at the baseline level, following common tradition in CGE modeling. Moreover, the total government expenditure is allocated to various services (e.g., public administration) at the same proportion as in the base case. The remaining government income is saved after deducting the transfers. In CGE modeling, savings of the government is also referred to to public savings.

A government decision on the rates of any tax (income, excise, duty) reverberates throughout the economy through production, consumption, and trade channels. For example, if the government increases production tax rate, it will be passed to intermediate and final consumption as well as exports. It increases costs of production in all sectors and ultimately reduces household welfare. The reverse would happen if the government cuts production taxes. When a carbon tax is introduced and its revenue is used to cut production tax, both taxes affect throughout the economy through production, consumption and trade channels, the model calculates the net effect capturing all interactions between various the production sectors, between production and consumption sectors, between domestic production and imports, between domestic consumption and exports, and every variables in the model (e.g., wage rate, cost of capital, prices of goods and services).

In the case of international trade, demand for imports is modeled using a CES functional form that aggregates a domestically produced good with its imported components. An output from

[10] Examples of household transfers to government are social security and other social contributions, fines penalties and forfeits. Dividends or repaying loans to the general government, rents to public properties, and social welfare contributions on behalf of their employees are examples of enterprise transfers to the government. Examples of the rest of the word transfers to government are grants received from foreign governments and international organizations.

a sector is allocated for domestic and foreign consumption (exports) using a constant elasticity of transformation (CET) functional form. Some emission-intensive sectors, such as oil and gas, chemicals and mining of minerals and metals produce major exported commodities in Egypt (Serag et al. 2022).

A CGE model assumes that an economy remains in equilibrium regarding goods and services, factor markets, savings and investments. Total savings in the economy is the sum of public savings, household savings, and foreign borrowings, which is equalized with total investment as one of the several conditions for general equilibrium. The foreign borrowing is calculated through a macroeconomic equilibrium condition which suggests that total outflows from the economy (payments to imports, remittance flowing out of country, transfers from governments, households and enterprises to the rest of the world) is equal to the total inflows to the economy (exports, remittances, transfers from rest of the world to households, governments and enterprises and foreign borrowings). The total investment is equal to sum of capital goods (gross fixed capital formation and inventory). The investment increases the stock of the capital (machines, factories). Firms gets services from the capital stock as illustrated in Figure 2.

The goods and services equilibrium assumes that the total demand for each good and service (domestic demand plus exports) equals its total supply (domestic supply plus imports). The factor market assumes that the total demand for labor and capital is equal to their supplies. Labor and capital are mobile across sectors, but not internationally, and their total supply or endowment for a given year is fixed. Labor prices (wage rate) and capital (user costs of capital) are different across the sectors, the different factor prices across the sectors provide incentives for factor mobility. World price and exchange rate are exogenous to the model, the latter also serves as the price numeraire.

Some assumptions in a general equilibrium model may not necessarily be realistic. For example, it assumes perfectly competitive markets and the market determines the prices. In reality, particularly in the context of many developing countries, including Egypt, these assumptions reflect a simplification of the reality. In a single-period static model, factor mobility and investment-saving balances are also not realistic. However, reflecting the actual situations in a model, no matter whether it an economic model or physical model, is not possible. Afterall, it is a model. Modelers try to reflect as close as possible depending on the data and information available.

2.2 Data

The main data needed for the study is a social accounting matrix (SAM) for Egypt. We used the SAM for 2019, jointly prepared by Egypt's national statistical office - the Central Agency for Public Mobilization and Statistics (CAPMAS), and the International Food Policy Research Institute (IFPRI). The SAM and detailed documentation of how the SAM was prepared is publicly available (Serag et al. 2021). We have further worked on the same and mapped the sectors and commodities to those needed for our analysis (see Table 1). For example, detailed agriculture commodities are unnecessary in our analysis as the agriculture sector is relatively less energy and emission intensive. Therefore, we aggregated all crops, fruits and vegetables, fishery, and forestry in one sector: agriculture and forestry. It helps us present our results clearly and focus on the sectors that are energy- and/or emission-intensive. The SAM also provides data by household income group, which allows us to conduct the distributional analysis. The SAM is the latest available for Egypt.

The SAM indicates that commercial services, including tourism services (hotels, restaurants), financial services, real estate, and business services, accounted for highest share of gross output (17%) in 2019 followed by the energy sector (crude oil and natural gas production, petroleum refinery and electricity sector), which accounts for 15% of the gross output. The agriculture sector that includes forestry and fishery accounted for 10% of the gross output. Commercial services also accounted for the highest share (27%) in total export of goods and services in 2019, followed by the transportation goods and services (17%) and chemicals and fertilizers (10%). The rich households (HH Quintile 5) received more than 40% of the total household income in 2019, whereas poor households (HH Quintile 1) received only 4% of the total household income. Taxes accounted for 99% of the total government revenues in 2019. There are five types of taxes – sales tax, corporate income tax, personal income tax, import duties and others, which accounted for, respectively 48%, 31%, 13%, 6% and 1% of the total government revenues. The fuel subsidy was equivalent to 31% of the total government revenue. Fossil fuel combustion accounts for 80% of the total GHG emissions in the country (World Bank, 2022b). The carbon tax policy analyzed in this study reduces CO_2 emissions from fossil fuel combustion.

The elasticity parameters include the elasticities of substitution used in the various tiers of production sector modeling and modeling of international trade (imports and exports). Unfortunately, no estimation of the elasticity of substitution is available for Egypt. This is a common problem for many developing countries. The only source is existing studies. We used values of elasticity of substitution from Timilsina and Sebsibe (2023) and Mosa (2019). Both of these studies are for Ethiopia. We could not find other countries with closer economic structures to Egypt that have estimated the elasticities of substitution.

3. Scenarios for Policy Simulation

The study considers two pricing policies for reducing CO_2 emissions: removing fossil fuel subsidies and introducing a carbon tax. The carbon tax rate is EGP600/tCO2, equivalent to US$20/t$CO_2$ in 2023 and 36/tCO_2 in 2019.[11] We have developed one baseline scenario, representing current policies,[12] and four illustrative scenarios depending on how the saved subsidies and carbon tax revenues are recycled into the economy. These scenarios are defined in Table 2. It is possible to have many more scenarios; however, having too many scenarios may dilute the comprehensiveness of the study, obstruct the flow of the message, and lengthen the paper. A popular scenario in the literature, using tax revenues to cut income (wage, capital, or both) taxes, is inappropriate here. This is because the size of the saved subsidy and carbon tax revenues was much higher than the total income tax households pay. Note that household income tax accounts for only 13% of the total government revenue. Sales tax, corporate/production taxes and import duties account for, respectively, 48%, 31% and 6% of the total government revenue. It means this scenario will turn like the cash transfer scenario favoring high-income households (high-income households pay a higher tax).

[11] The annual average exchange rate between the United States dollar (US$) and Egyptian pound (EGP) increased from 16.8 in 2019 to 30 in 2023. Out of 31 national or sub-national economies that have introduced carbon tax to date, only 10 have a carbon tax rate higher than $36/tCO2 by the end of 2022 (World Bank, 2023).

[12] In this static model, the baseline scenario represents the economic situation presented by the Social Accounting Matrix (SAM), the main economic database used for the model. In the baseline, all variables and parameters, such as sectoral value added, outputs, labor, capital, intermediate consumption, household income and savings, government revenue, taxes, etc. are those presented in the SAM. The existing policies, such as fuel subsidies, are also presented in the SAM.

We have selected a single value for a carbon tax to focus on the variation in recycling design and subsidy reform alternatives, resulting in 13 simulations (four scenarios, 3 cases under each scenario, and a base case). The EGP 600/tCO_2 carbon tax is fairly high, and a carbon tax higher than this may not be appropriate for a developing country like Egypt. Outside of the EU, Canada, and New Zealand, carbon prices in most implementing jurisdictions are below this level (Carbon Pricing Dashboard). The EGP 600/tCO_2 rate also generates about the same amount of government revenue that the removal of fossil fuel subsidies saves, thereby providing similar ground to compare the general equilibrium effects between these policies.

Table 2: Definition of Scenarios

Scenario	Definition
Public investment	Saved subsidies and carbon tax revenues allocated for public investment (after repaying government's internal debt)
Equal transfer to households	Saved subsidies and carbon tax revenues rebated to all household income groups equally
Progressive transfer to households	Saved subsidies and carbon tax revenues rebated to different household income groups inversely proportional to their income. A household income group with the lowest income gets the highest rebate
Corporate income tax cuts	Saved subsidies and carbon tax revenues are recycled to cut corporate income taxes in sectors; tax revenues are reallocated to non-fossil fuel sectors inversely proportional to their emission intensity (a sector with a higher emission intensity gets a lower rebate)

Note: Under all scenarios, government revenue is kept neutral, meaning that only the government revenue excess of baseline level is recycled to the economy.

Under scenario 1 ('Public investment'), the government uses the carbon tax revenues for public investment. However, Egypt was realizing negative public savings (or public debt) in the base year. If there were no carbon tax revenue, other sources of government revenue (e.g., increased personal and corporate income tax, sales tax, import duty) would have been used to pay the debt. If the carbon tax revenue is used to pay the public debt, the other revenues that would have been used to pay public debt can be used for public investment. Thus, the end effect of this scenario is increased public investment. In the absence of carbon tax, if the government wants to increase the public investment, it needs to find other sources of revenues, as explained above (i.e., increased personal and corporate income tax, sales tax, import duty). In the second scenario ('Equal cash transfers to households'), the government equally distributes the saved subsidy and carbon tax revenues to all households as a cash transfer. In the third scenario ('Progressive cash transfers to households'), the government does the same as in the second scenario but saved subsidy and carbon tax revenues are distributed to different income groups of households inversely proportional to their income.[13] Scenarios 2 and 3 are the most important scenarios for analyzing the distributional effects of a carbon tax. While the poorer households get relatively higher cash transfers than richer households under scenario 2, they receive higher cash transfers than the richer households in absolute terms under scenario 3. In Scenario 4 ('Corporate income tax cuts'), the saved subsidy and carbon tax revenue are recycled to non-fossil fuel sectors inversely proportional to their CO_2 intensities. This means a sector with a higher CO_2 emission intensity gets a lower carbon tax revenue as a rebate. A low carbon intensive sector gets a higher rebate. In the equilibrium its products would be relatively cheaper increasing its domestic and export demands, thus expanding the sector.

4. Results and Discussion

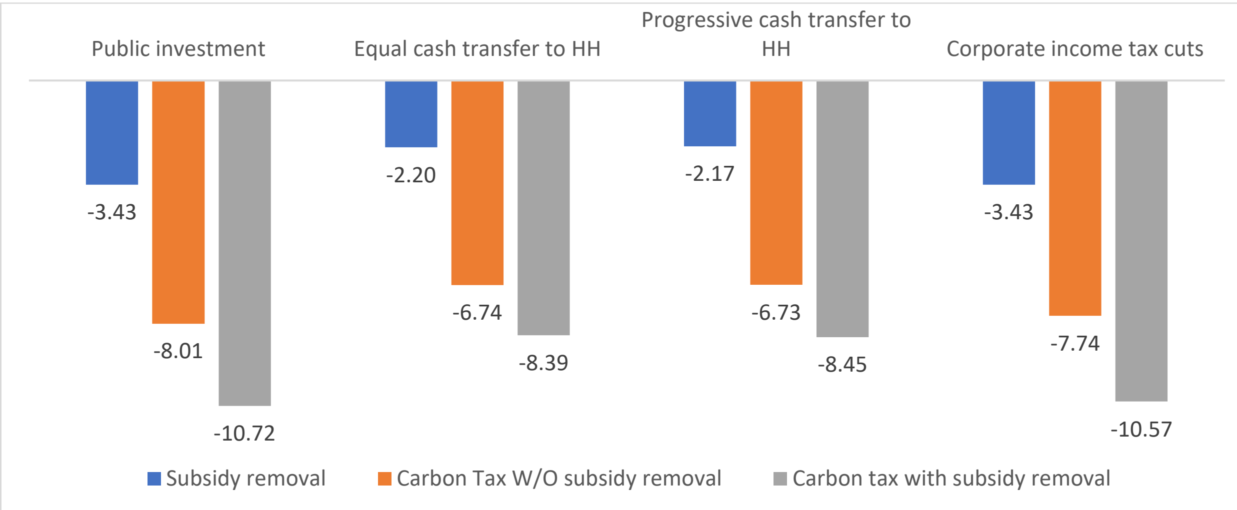
4.1 Impacts on CO_2 Emissions

Figure 3 presents the impacts on CO_2 emissions of the fossil fuel subsidy removal and the introduction of a carbon tax. The removal of subsidies on petroleum products (other fossil fuels do not have direct subsidies) would reduce CO_2 emissions by 2.2% to 3.4% from the base case depending upon the scheme to recycle the saved subsidy. The reductions come from a direct increase in consumer prices of petroleum products and their indirect impacts on other commodities. Removing petroleum products subsidies increases its price by 13.6% to 16.3% depending upon the saved subsidy recycling scheme. The carbon tax would cause a decrease in CO_2 emissions by 6.7% to 8.1% from the baseline when the existing subsidy on petroleum products is unaltered. If the carbon tax is introduced together with the removal of fossil fuel subsidies, the CO_2 reductions would be 8.4% to 10.7%. The higher reduction of CO_2 is due to the carbon tax compared to the subsidy removal case because the former impacts all fossil fuels, whereas the

[13] Let xi represents HH income of quintile i. The sum of inverse incomes, Y = 1/x1 + 1/x2+ ….. The share of rebate of quintile i, si = (1/xi)/Y. Since 1/x1 > 1/x2> …>1/x5. Lower income HH will receive higher tax rebate.

latter impacts only the price of petroleum products. The carbon tax and subsidy removal together would increase the prices of petroleum products by 28.5% to 31.5%.

Figure 3. Impacts on CO_2 emissions (% change from the base case)



Why are the emissions reductions lower when subsidy savings and carbon tax revenues are transferred to households equally or progressively as compared to other cases? The reason is an income-driven rebound effect: the cash transfers increase the real income of households, who in turn consume more fossil fuels than in the absence of such transfer, thereby diluting the emission reduction effects of pricing instruments (i.e., fossil fuel subsidy removal and carbon taxation) considered here.[14] The emission reductions are highest under the public investment scenario, because no rebound effect occurs under this scenario.[15] The emission reductions under the corporate income tax cuts scenario are slightly smaller as compared to those under the 'public investment' scenario because the recycling of saved subsidies and carbon tax revenues cause minor rebound effects although they are recycled only to non-fossil fuel sectors (inversely proportional to their emission intensities).

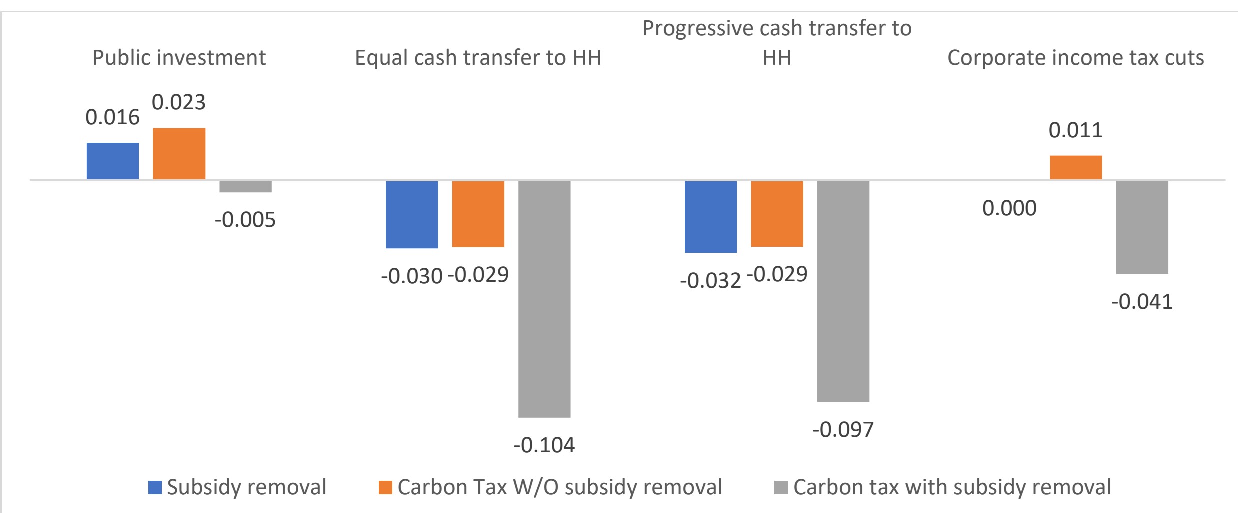
[14] The shares of energy (natural gas and electricity) in total household expenditures are 6.7%, 6.3%, 6.2%, 6.1% and 5.6% for household income groups 1, 2, 3, 4, and 5, respectively. Note that income group 1 refers to lowest income group and income group 5 refers to highest income group.

[15] Under the public investment scenario, the rebound effect does not occur, because government expenditure (i.e., consumption) goes to public administration, business services, health, education, defense and security. Government does not directly consume fossil fuels. Moreover, we have fixed government's expenditure at the same level in the baseline.

4.2 Impacts on GDP

Figure 4 presents the impacts on GDP of the fossil fuel subsidy removal and introduction of the carbon tax. The impacts are relatively low, varying from -0.04% to 0.02%. The impacts are rather non-linear; although the removal of fossil fuels subsidies and the introduction of carbon tax increase consumer prices of fossil fuels, their impacts are different. The removal of subsidies mainly affects petroleum products, as there were no subsidies on coal and natural gas. On the other hand, the carbon tax effect is felt by all fossil fuels – more by coal due to its high emission intensity. Although the percentage changes in GDP are small, they still amount to billions of EGP. Note that when both policies are implemented (i.e., subsidy removals and introduction of carbon tax), fuel prices rise even more. The adverse economic impacts of increased fuel prices cannot be fully compensated by the increased revenue due to these policies (although they may be balanced by environmental benefits). Thus, GDP impacts would be negative even in the case of the 'public investment' scenario. Under other scenarios, the GDP losses due to the combined policies are much higher than the individual policy.

Figure 4. Impacts on GDP (% change from the base case)



The change in GDP can be explained through the changes in its components (i.e., household consumption, government consumption, investment, exports, and imports) and their share in the base case. Table 3 shows the share of these components in the baseline. More than 80% of GDP in the baseline is contributed by household consumption. Imports and exports also have important roles to explain the GDP change. Government consumption which accounts for 9% of the GDP does not contribute to change in GDP as government consumption under the policy scenarios are kept the same as in the base case.

Table 3. Share of GDP components in the base case

GDP components	Share in the base case
Household consumption	81.0%
Government consumption	8.8%
Investment	19.0%
Exports	20.9%
Imports	-29.6%

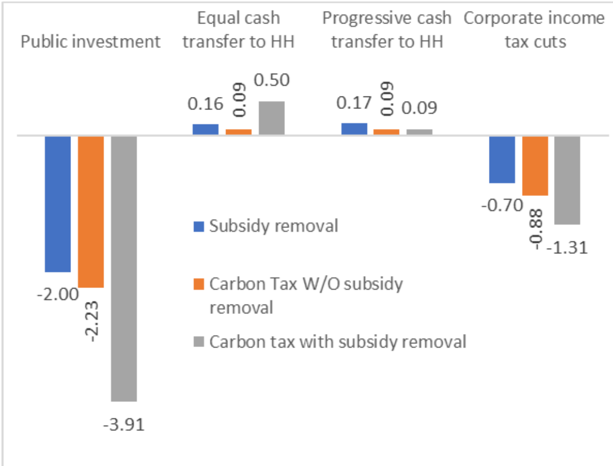
Based on Table 3 and Figure 5, it can be concluded that the GDP impacts under the public investment scenario are mainly determined by the change in investment. The GDP impacts under the household cash transfer, either equally or progressively, are determined mainly by the changes in exports. All components of the GDP, except government consumption, have influenced the GDP impacts in the case of corporate income tax cuts.

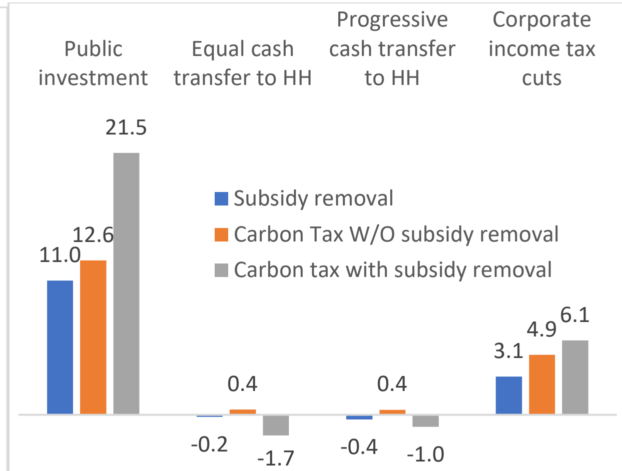
Figure 5. Impacts on GDP components (household consumption, government consumption, capital goods, imports, and exports)

% Change from the base case

(a) Household consumption

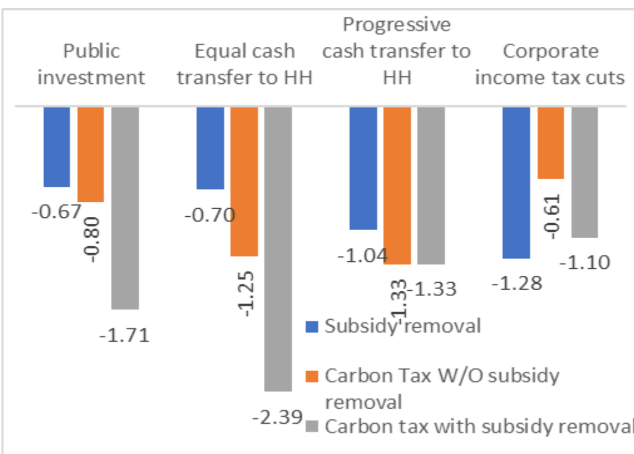
(b) Investment

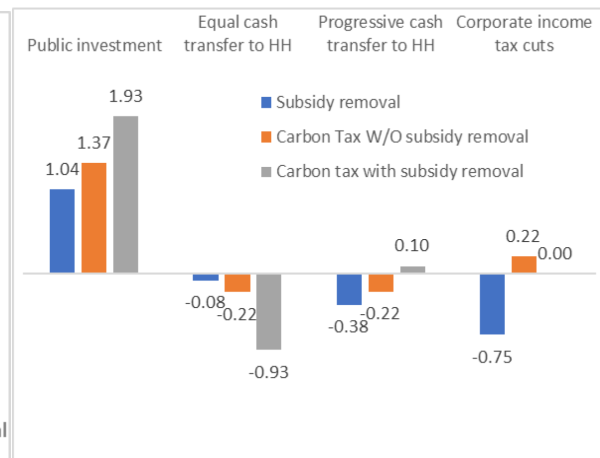




(c) Exports

(d) Imports





4.3 Sectoral Economic Impacts

Impacts on sectoral outputs of fossil fuel subsidy removal and introduction of a carbon tax are presented in Table 4. We can derive several important insights from the table. First, the sectoral impacts are significantly different between the subsidy removal and carbon tax cases, although both ultimately increase the prices of fossil fuels. The difference is that these two pricing instruments impact various sectors differently. The removal of fossil fuel subsidies impacts production by increasing the prices of petroleum products, as other fossil fuels (coal and natural gas) do not have subsidies. Sectors with higher shares of the total consumption of petroleum products, such as the electricity and transport sectors, get affected relatively higher (i.e., relatively higher loss of their sectoral outputs due to increases in petroleum prices resulting from subsidy removal). Besides the demand-side effects, sectoral outputs are also affected by supply-side effects. The removal of fossil fuel subsidies reduces the domestic demand for petroleum products from 7% to 16%, depending on the scenario. Since the demand decreases, its production also decreases to keep the demand and supply in equilibrium. When the total demand for petroleum products decreases, the demand for its main input, crude oil, and its supply decreases.

The carbon tax increases the price of high carbon fuels, such as coal and petroleum products, relatively higher, thereby decreasing the outputs of the sectors producing these fuels and the outputs of the main sectors consuming these fuels. The carbon tax causes the sectoral outputs of the petroleum refinery sector, the natural gas sector, the electricity sector, and the transport sector to decline. When subsidy removal and carbon tax policies are combined, the impacts get significantly amplified, reducing the sectoral outputs of the petroleum sector from 13.8% to 15.9%, depending upon the scenario.

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Table 4. Impacts on sectoral outputs (% change from the base case)

	Public investment			Equal cash transfer to HH			Progressive cash transfer to HH			Corporate income tax cuts		
	Subsidy	CTAX	Both	Subsidy	CTAX	Both	Subsidy	CTAX	Both	Subsidy	CTAX	Both
Agriculture	-0.83	-0.72	-1.50	1.09	1.38	2.51	1.16	1.43	2.50	0.07	0.13	0.10
Oil	-9.50	-8.47	-16.06	-8.40	-7.24	-13.96	-8.36	-7.23	-14.02	-9.22	-8.07	-15.54
Natural Gas	1.15	-8.20	-7.25	2.65	-6.77	-4.48	2.66	-6.76	-4.44	1.22	-7.69	-6.70
Other mining	2.57	2.73	4.62	-0.30	-0.37	-1.20	-0.33	-0.37	-1.10	1.91	1.99	3.42
Food, beverage, tobacco	-1.07	-1.00	-2.00	1.03	1.29	2.37	1.09	1.33	2.37	0.60	0.66	1.18
Textile	-0.54	-0.57	-1.07	1.39	1.55	3.00	1.45	1.57	2.90	5.66	5.62	11.24
Petroleum products	-9.44	-8.35	-15.90	-8.33	-7.12	-13.80	-8.30	-7.11	-13.85	-9.21	-7.99	-15.45
Chemicals	-0.26	-0.74	-1.06	0.26	-0.13	0.10	0.30	-0.14	-0.03	0.86	0.25	0.83
Non-metals	5.82	6.70	11.27	-0.29	0.03	-1.34	-0.40	0.02	-0.99	3.63	4.46	7.40
Metals	5.12	6.11	10.02	-1.17	-0.61	-2.66	-1.17	-0.62	-2.64	3.85	4.59	7.52
Machinery	6.71	7.82	13.15	-0.49	0.10	-1.50	-0.52	0.09	-1.41	8.66	9.63	17.43
Other manufacturing	2.21	2.37	4.10	0.77	0.85	1.23	0.80	0.87	1.23	2.33	2.34	4.18
Electricity	-3.50	-4.62	-7.65	-2.08	-3.10	-4.85	-2.06	-3.09	-4.87	-5.22	-4.26	-9.00
Construction	10.84	12.48	21.20	-0.08	0.57	-1.38	-0.26	0.55	-0.77	4.71	6.19	9.71
Trade	-0.55	-0.45	-1.08	-0.87	-0.90	-1.86	-1.01	-0.95	-1.70	0.37	0.67	1.24
Transport	-2.24	-2.15	-4.13	-0.61	-0.36	-0.76	-0.53	-0.31	-0.77	-1.42	-1.39	-2.73
Commercial services	-0.01	0.07	-0.02	0.70	0.83	1.46	0.68	0.81	1.44	0.59	0.68	1.16
Public services	-0.45	-0.46	-0.76	0.45	0.61	1.23	0.51	0.59	0.92	0.15	-0.04	-0.02
Other services	-0.63	-0.56	-1.11	0.66	0.88	1.63	0.69	0.87	1.47	1.68	1.70	3.28

The sectoral impacts vary significantly across the schemes to recycle the saved subsidy and carbon tax revenues. The variations are more prominent in less energy- or emission-intensive sectors. See the case of the textile sector, a labor-intensive sector. Its output declines under the ‘public investment’ scenario, but its output significantly increases under the ‘corporate tax cuts’ scenario because it gets higher corporate tax cuts relative to emissions payments, due to its lower emission intensity. In the case of the food, beverage and tobacco sector, output declines under the public investment scenario, whereas output increases when cash is transferred to households equally or progressively. The cash transfer increases the real income of households, which, in turn, increases their demand for food, beverages and tobacco. As the demand increases, so does its supply in the equilibrium. Under the public investment scenario, outputs from the construction sector would increase by 10% (subsidy removal case) to 21% (subsidy removal and carbon tax case), whereas its output decreases under the household cash transfer scenario. The results, thus, reveal that the sectoral impacts, particularly that of non-fossil fuels or less emission-intensive fuels, are highly sensitive to the schemes to recycle the saved fuel subsidies and carbon tax revenues.

4.4 Impacts on Public Finance

Figure 6 presents savings from subsidy removals and carbon tax revenues under the alternative scenarios. Incidentally, the savings from subsidy removals and carbon tax revenues have about the same magnitudes under a scenario. The carbon tax would increase government revenue by 11% to 11.2% (Figure 7). Similarly, the saved subsidy amounts to 11.8% to 12% of government revenue (Figure 7). The saved subsidies and carbon tax revenues together account for 21.2% to 21.5% of the total government revenue. Removing fuel subsidies and introducing the carbon tax would increase the effective government budget by more than 20% from the baseline. The increased revenue is used for various purposes, as indicated in Figures 6 and 7 (i.e., public investment, transfer to households, cutting corporate income taxes). It can be used for many other purposes not investigated in this analysis. Note that when the surplus revenue is recycled to cut corporate income taxes, it would be enough to reduce the corporate taxes by more than 50%. Similarly, as discussed in the next sub-section, when the saved subsidy and carbon tax revenue is recycled to households, total household income would increase approximately by 3%. The saved subsidy and carbon tax revenue would be enough to compensate the government’s savings (or repay the government debt if the government wants to do so), which have been consistently negative for several years, by 48% (i.e., government savings would be 48% less negative than in the base case).

Figure 6. Savings from subsidy removal and carbon tax revenues (Billion EGP)

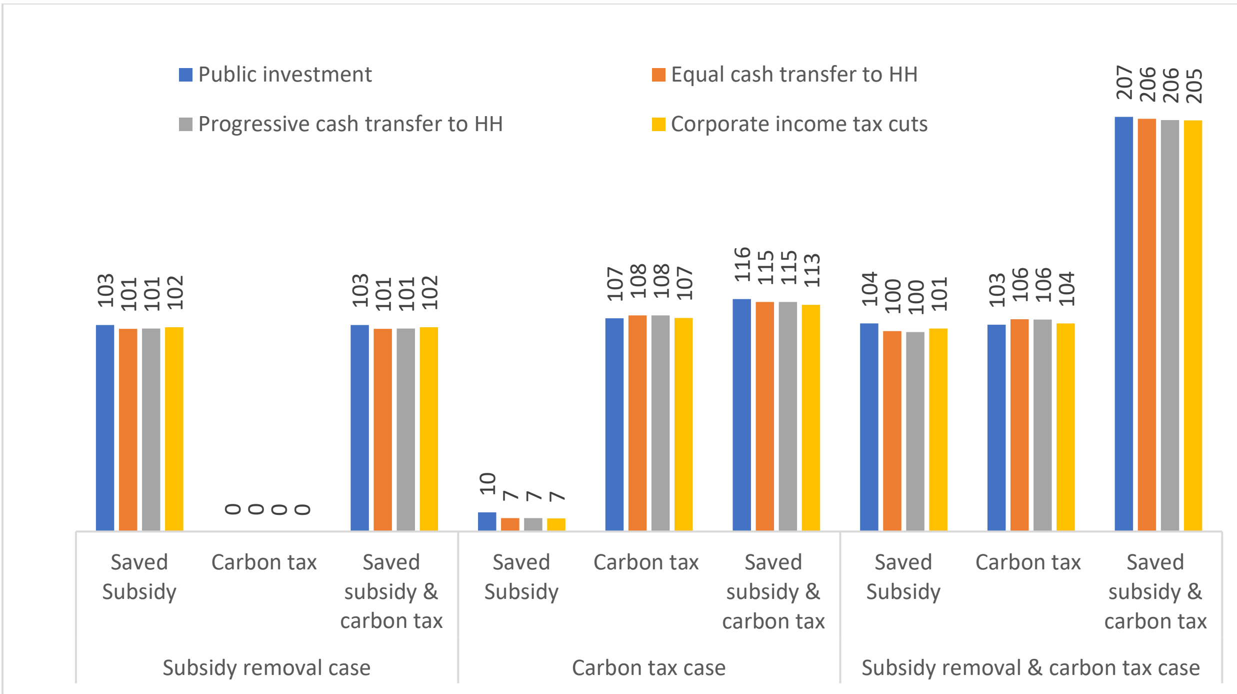
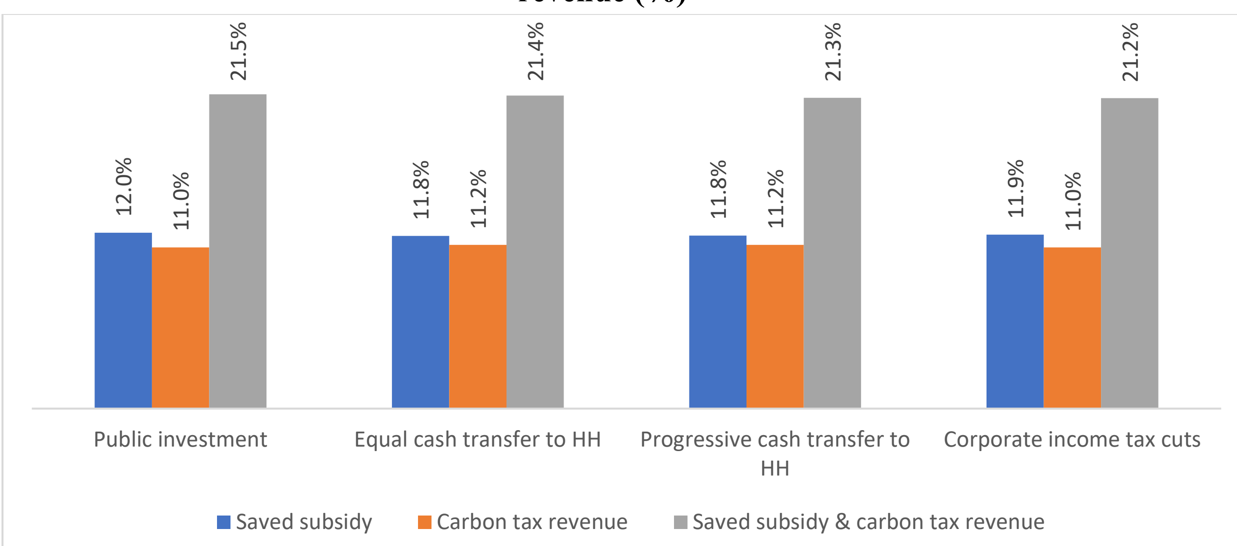


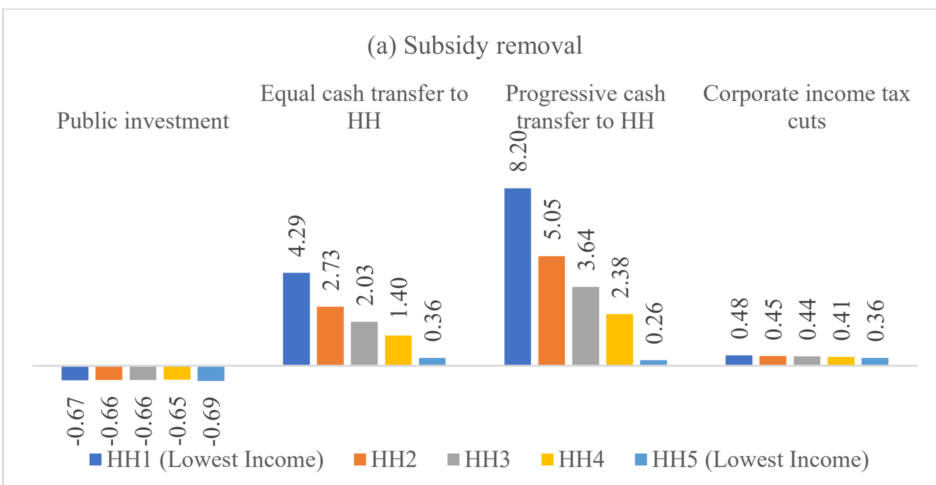
Figure 7. Saved subsidy and carbon tax revenues as a percentage of total government revenue (%)

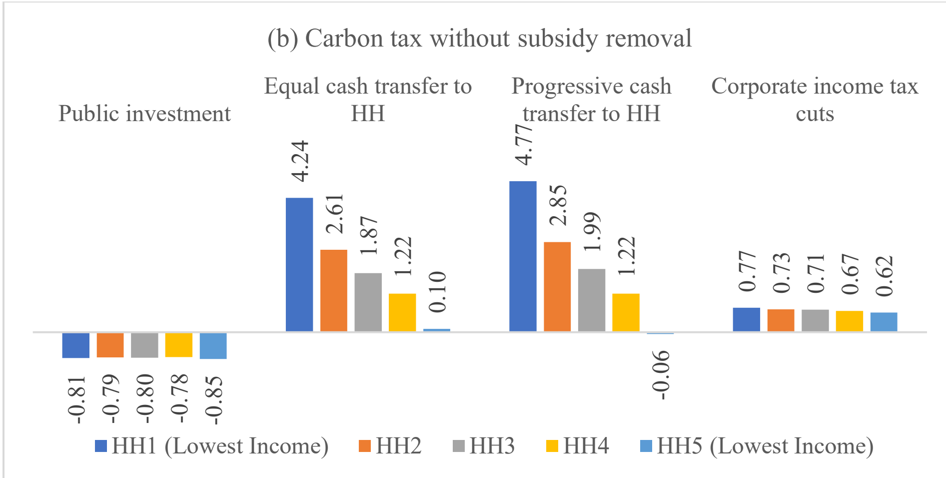


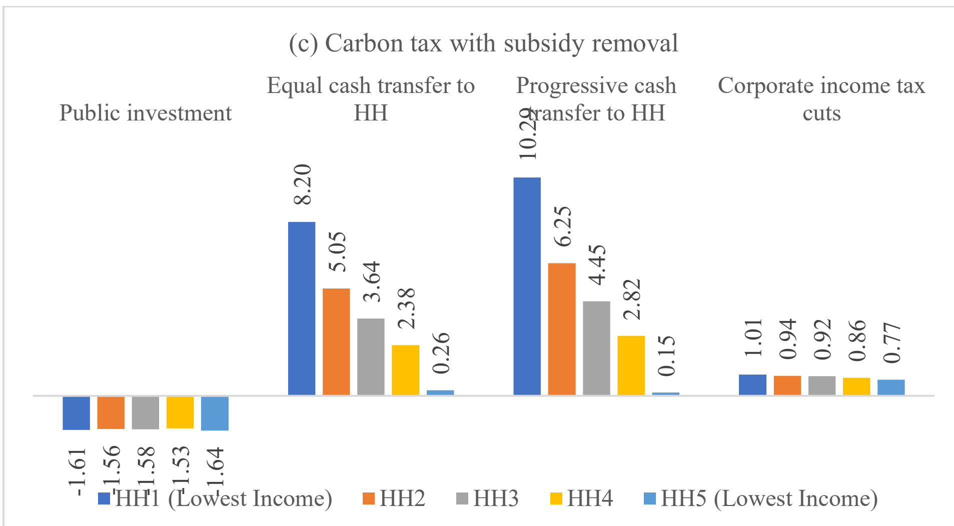
4.5 Distributional Impacts

We use household income to measure the distributional impacts of the household income groups. Figures 8a, 8b, and 8c present the percentage change in house income under the subsidy removal, carbon tax without subsidy removal, and carbon tax with subsidy removal cases, respectively. All groups of households gain due to fossil fuel subsidy removals when the saved subsidy is transferred to households either equally or progressively. The gain is higher for poorer households than for richer households. The result indicates that removing fossil fuel subsidies can be progressive if the saved subsidy is given to households equally or inversely proportional to their income. The income of all groups of households also increases under the corporate tax cut scenario. However, the increase is much smaller than cash transfer cases, especially for low-income households. Under the public investment scenario, the income of all household groups declines. This is because the public investment mostly helps expand the production capacity instead of directly contributing to household income and consumption.

Figure 8. Impacts on household income (% change from the baseline)







If the carbon tax is introduced without removing the fossil fuel subsidies, the magnitudes and patterns of distributional impacts are like those of fuel subsidy removal cases, with one exception. The highest income group would face a small decrease in their income when carbon tax revenue is transferred to households based on the inversion of their income, which makes the highest income group receive the lowest cash transfer. The similar pattern of the distributional impacts between the subsidy removal case and carbon tax case is that both instruments mainly affect petroleum products consumption of the households. The carbon tax has a higher impact on coal, but coal is not used by households. Natural gas is also used by households and gets affected by the carbon tax, but the impacts would be much smaller than petroleum products because of the much less consumption of the latter by households than the former. When the subsidy removal and the carbon tax are implemented together, the magnitude of impacts increases, whereas the distributional pattern does not.

4.6 Sensitivity Analysis

To confirm that the results from model simulation are robust, sensitivity analyses on key model parameters are carried out. The main model parameters are elasticities of substitution as shown in Figure 2. The values of the elasticities of substitution are first decreased by 50% and then increased by 50%. The key sensitivity results (impacts on GDP, total household income and CO_2 emissions) under all scenarios are presented in Table 5. For the comparison purpose, the corresponding results from the main analysis are also presented in the same table. The sensitivity results show that change in the values of the elasticities of substitution does not change the direction of the impacts, whereas magnitude of the impacts, as expected, can change. The changes in magnitudes are relatively small when the values of the elasticities of substitution are changed significantly (±50%).

Table 5. Results of sensitivity analysis (% change from the base case)

	Public Debt repayment			Transfer to households (Equal)			Transfer to households (progressive)			Corporate tax cuts		
	Subsidy	CTAX	Both	Subsidy	CTAX	Both	Subsidy	CTAX	Both	Subsidy	CTAX	Both
When values of elasticity of substitution are increased by 50%												
GDP	-0.07	-0.08	-0.19	-0.04	-0.05	-0.15	-0.04	-0.15	-0.15	0.01	0.00	-0.04
Income	-3.76	-4.32	-7.15	3.02	2.22	4.27	3.02	2.22	4.28	0.84	0.07	0.44
Emissions	-2.37	-7.81	-9.86	-2.18	-7.58	-9.43	-2.16	-7.57	-9.40	-2.68	-8.02	-10.21
When values of elasticity of substitution are reduced by 50%												
GDP	-0.02	-0.02	-0.06	-0.01	-0.01	-0.05	-0.01	-0.05	-0.05	0.01	0.01	0.00
Income	-3.85	-4.33	-7.42	3.96	3.20	5.94	3.97	3.21	5.96	1.72	0.98	1.90
Emissions	-2.61	-6.14	-8.29	-2.07	-5.62	-7.41	-2.05	-5.60	-7.39	-3.16	-6.61	-9.14
Results from the main analysis												
GDP	-0.05	-0.05	-0.13	-0.03	-0.03	-0.10	-0.03	-0.10	-0.10	0.01	0.00	-0.02
Income	-3.85	-4.39	-7.40	3.41	2.62	4.95	3.42	2.62	4.96	1.19	0.43	0.98
Emissions	-2.53	-7.02	-9.13	-2.16	-6.65	-8.49	-2.14	-6.63	-8.47	-2.95	-7.35	-9.72

5. Conclusions and Policy Implications

Egypt is a large emitter of GHG emissions, ranking 24th position in the world and the 3rd position in the MENA region. The country has set a target of reducing 33% of its emissions by

2030 from the level that would happen otherwise (baseline). However, the country still provides some subsidies to fossil fuels, particularly petroleum products. Fossil fuel subsidies cause higher emissions than in the situation in which they are absent. Removal of fossil fuel subsidies thus can be considered a pricing instrument to reduce GHG emissions. Developing a computable general equilibrium model for Egypt, this study analyzes the environmental, macroeconomic, public finance, and distributional impacts of fossil fuel subsidy removal and introduction of a carbon tax. It also investigates how these impacts vary across alternative schemes to recycle the saved subsidy and carbon tax revenues.

The study shows that eliminating existing subsidies on petroleum products and introducing the EGP 600/tCO_2 carbon tax would reduce Egypt's national CO_2 emissions by 11% from the baseline (i.e., the situation with existing fuel subsidies and no carbon tax). The GDP impacts vary across the revenue recycling schemes but remain small (-0.04% to +0.02%). Removal of subsidies and introducing a carbon tax increase household income in all cases except the scenario where they are used for public investment. Both policies are progressive (i.e., cause higher household income for the poor than the rich) when the saved subsidies and carbon tax revenues are transferred to households equally. Poor households realize further income increases when recycling is implemented inversely proportional to household income.

Considering the economic and climate change mitigation impacts, removal of fossil fuel subsidies and introduction of a carbon tax would not be harmful to the Egyptian economy. The savings from subsidy removal and revenues from the carbon tax could increase the government revenue by more than 20%. This increased revenue could be an incentive from the public finance perspective in the country, which has been running with a high public debt for many years. However, the government must be very cautious on how to use the savings and additional revenues. If the savings and additional revenues are channeled to benefit poor households, these policies would be progressive, and their implementation may not face public resistance or political reluctance.

It is also important to investigate potential sectoral consequences if these policies are considered for implementation. These policies not only directly affect (i.e., increase) prices of energy commodities, but also affect prices of non-energy commodities indirectly. The changes in relative prices of non-energy commodities are highly sensitive to schemes to recycle the saved subsidies and carbon tax revenues. Instead of considering a single indicator, such as impacts on

GDP, implementation of policies should consider various attributes including economic impacts, emission reduction potentials, impacts on commodity prices and household income, distribution of the income effects across the household groups, particularly, the low-income households, and impacts on trade balance.

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Appendix A

Detailed Description of the Model

A.1 Modeling the production sectors

The production sectors are modeled through nested CES functions as illustrated in Figure 2. The first tier of the CES production function is given by

$$QA_i = \alpha_i^A \cdot [\delta_i^A \cdot QVA_i{}^{\rho_i^A} + (1-\delta_i^A) \cdot QINTA_i{}^{\rho_i^A}]^{1/\rho_i^A} \quad \text{(A1)}$$

where QA_i is the total production of sector i, QVA_i and $QINTA_i$ are the input of value-added and intermediate input in sector i, respectively. δ_i^A and α_i^A are the share parameter and efficiency parameter; ρ_i^A is the substitution elasticity parameter between value-added and intermediate input, and $\sigma_i^{A\frac{1}{(1-\rho_i^A)}}$, $\sigma_{i,}^A$ is the substitution elasticity between value-added and intermediate input. Optimal factor input under total production:

$$\frac{PVA_i}{PINTA_i} = \frac{\delta_i^A}{1-\delta_i^A} \cdot \left(\frac{QINTA_i}{QVA_i}\right)^{1-\rho_i^A} \quad \text{(A2)}$$

where PVA_i and $PINTA_i$ are the price of value-added and intermediate composite of energy and non-energy inputs in sector i. Relationship of price of total output:

$$PA_i \cdot QA_i = PVA_i \cdot QVA_i + PINTA_i \cdot QINTA_i \quad \text{(A3)}$$

where PA_i is the producer price of sector i.

The composite energy and non-energy commodities are given as:

$$QINTA_i = \alpha_i^{ne} \cdot [\delta_i^{ne} \cdot QNE_i{}^{\rho_i^{nee}} + (1-\delta_i^{ne}) \cdot QE_i{}^{\rho_i^{nee}}]^{1/\rho_i^{nee}} \quad \text{(A4)}$$

where QNE_i and QE_i are the input of non-energy aggregate and energy composite in sector i, respectively, δ_i^{ne} and α_i^{ne} are the share parameter and efficiency parameter; ρ_i^{nee} is the substitution elasticity parameter between the input of non-energy intermediates and energy, and $\sigma_i^{nee} = \frac{1}{(1-\rho_i^{nee})}$, σ_i^{nee} is the substitution elasticity between the non-energy intermediate inputs and energy.

The optimal demands for prices are derived as follows:

$$\frac{PNE}{PE_i} = \frac{\delta_i^{ne}}{1-\delta_i^{ne}} \cdot \left(\frac{QE_i}{QNE_i}\right)^{1-\rho_i^{ne}} \tag{A5}$$

where PNE and PE are the price of the non-energy aggregate and energy composite respectively. The relationship of price of the input of non-energy aggregate and energy component are given as:

$$PINTA_i \cdot QINTA_i = PNE_i \cdot QNE_i + PE_i \cdot QE_i \tag{A6}$$

The quantity of intermediate input of non-energy commodity:

$$QNEA_{j,i} = ica_{j,i} \cdot QNE_i \quad j \in individual\ non-energy\ commodity \tag{A7}$$

The price of intermediate input:

$$PNEA_i = \sum_j ica_{j,i} \cdot PQ_i \quad j \in individual\ non-energy\ commodity \tag{A8}$$

where $QNEA_{j,i}$ is the quantity of input of non-energy commodity j as non-energy intermediate aggregate input of sector i, $ica_{j,i}$ is intermediate input coefficient, denoting the proportion of the input of non-energy commodity j in the total non-energy intermediate aggregate input of sector i.

The aggregation of labour and capital:

$$QVA_i = \alpha_i^{va} \cdot [\delta_i^{va} \cdot QLD_i^{\rho_i^{va}} + (1-\delta_i^{va}) \cdot QKD_i^{\rho_i^{va}}]^{1/\rho_i^{va}} \tag{A9}$$

where QLD_i and QKD_i are the input of labor and capital in sector i respectively, δ_i^{va} and α_i^{va} are the share parameter and efficiency parameter; ρ_i^{va} is the substitution elasticity parameter between labour and capital, and $\sigma_i^{va} = \frac{1}{(1-\rho_i^{va})}$, σ_i^{va} is the substitution elasticity between labour and capital. The demand and price relationship are defined in the two equations below:

$$\frac{WL_i}{PK_i} = \frac{\delta_i^{va}}{1-\delta_i^{va}} \cdot \left(\frac{QKD_i}{QLD_i}\right)^{1-\rho_i^{va}} \tag{A10}$$

$$PVA_i \cdot QVA_i = WL \cdot QLD_i + PK_i \cdot QKD_i \tag{A11}$$

where WL and PK are the price of the input of labour and capital in sector i respectively.

The aggregation of fossil fuels and electric power is given by

$$QE_i = \alpha_i^{ec} \cdot [\delta_i^{ec} \cdot QEF_i^{\rho_i^{ec}} + (1-\delta_i^{ec}) \cdot QEE_i^{\rho_i^{ec}}]^{1/\rho_i^{ec}} \tag{A12}$$

where QEF_i and QEE_i are the input of fossil fuels and electric power in sector i respectively, δ_i^{ec} and α_i^{ec} are the share parameter and efficiency parameter; ρ_i^{ec} is the substitution elasticity parameter between the input of fossil fuels and electric power, and $\sigma_i^{ec} = \frac{1}{(1-\rho_i^{ec})}$, σ_i^{ec} is the substitution elasticity between the input of fossil fuels and electric power. Under the optimal conditions, the price and quantities are related as follows:

$$\frac{PEF_i}{PEE_i} = \frac{\delta_i^{ec}}{1-\delta_i^{ec}} \cdot \left(\frac{QEE_i}{QEF_i}\right)^{1-\rho_i^{ec}} \quad \text{(A13)}$$

$$PE_i \cdot QE_i = PEF_i \cdot QEF_i + PEE_i \cdot QEE_i \quad \text{(A14)}$$

where PEF_i and PEE_i are the price of the input of fossil fuels and electric power in sector i respectively.

In a similar manner, demand and prices of coal, petroleum products and natural gas are calculated following the structure in Figure 2.

Modeling the international trade

The following Constant Elasticity of Transformation (CET) function is adopted to describe the allocation of supply between domestic market and export:

$$QA_i = \alpha_i^t \cdot \left[\delta_i^t \cdot QDA_i^{\rho_i^t} + (1-\delta_i^t) \cdot QEX_i^{\rho_i^t}\right]^{\frac{1}{\rho_i^t}},\ \rho_i^t > 1 \quad \text{(A15)}$$

where QDA_i and QEX_i are the supply of commodity produced in sector i to domestic market and export respectively, δ_i^t and α_i^t are the share parameter and efficiency parameter; ρ_i^t is the transformation elasticity parameter between domestic market supply and export, and $\sigma_i^t = \frac{1}{(\rho_i^t-1)}$, σ_i^t is the transformation elasticity between domestic market supply and export. Under the optimal condition, the demand and prices are calculated as follows:

$$\frac{PDA_i}{PEX_i} = \frac{\delta_i^t}{1-\delta_i^t} \cdot \left(\frac{QEX_i}{QDA_i}\right)^{1-\rho_i^t} \quad \text{(A16)}$$

$$PA_i \cdot QA_i = PDA_i \cdot QDA_i + PEX_i \cdot QEX_i \quad \text{(A17)}$$

where PDA_i and PEX_i are the domestic and export prices of commodity produced from sector i.

Exchange rate (EXR) converts the world price to domestic price as follows:

$$PEX_i = \overline{PWE}_i \cdot EXR \tag{A18}$$

where $\overline{PWE}_i$ is the international market price of exported commodity i,and EXR is the exchange rate.

The following CES function is adopted to describe the choice between domestic and import commodity:

$$QQ_i = \alpha_i^q \cdot \left[\delta_i^q \cdot {QDC_i}^{\rho_i^q} + (1 - \delta_i^q) \cdot {QM_i}^{\rho_i^q}\right]^{1/\rho_i^q} \tag{A19}$$

where QQ_i , QDC_i and QM_i are the demand for composite commodity i, domestic commodity i and import commodity i, respectively, and δ_i^q and α_i^q are the share parameter and efficiency parameter; ρ_i^q is the substitution elasticity parameter between domestic and import commodity, and $\sigma_i^q = \frac{1}{(1-\rho_i^q)}$, σ_i^q is the substitution elasticity between domestic and import commodity.

First order condition:

$$\frac{PDC_i}{PM_i} = \left(\frac{\delta_i^q}{1-\delta_i^q}\right) \cdot \left(\frac{QM_i}{QDC_i}\right)^{1-\rho_i^q} \tag{A20}$$

where $PDC_{i,r}$ is the price of domestic commodity i, $PM_{i,r}$ is the price of import commodity i.

The composite commodity price is the weighted mean of the price of domestic and import commodity:

$$PQ_i \cdot QQ_i = PDC_i \cdot QDC_i + PM_i \cdot QM_i \tag{A21}$$

where PQ_i is the price of the composite of domestic and imported commodity i.

The exchange rate conversion between the price of import commodity in the international market and ETB is:

$$PM_i = \overline{PMW}_i \cdot (1 + tm_i) \cdot EXR \tag{A22}$$

where $\overline{PMW}_i$ is the international market price of import commodity i, and tm_i is the import tariff rate of import commodity i.

A.3 Modeling household behavior

Households are disaggregated into five categories (quintiles) based on their income. For each quantile, the households' income is composed of wage income, capital rents and transfer payments from domestic institutions and foreign countries. It is given as:

$$YH = \sum_i WL \cdot QLD_i + \sum_i WK \cdot QKD_i + TGH + TWH.EX \quad \text{(A23)}$$

where YH is the income of households; TGH and TWH are the transfer payments from government foreign countries (or rest of the world), respectively. Based on Cobb-Douglas functional form, the household consumption by each income group is determined as follows:

$$PQi\,.\,QHi = mpc\,.\,\gamma_i\,.\,((1-th).YH) \quad \text{(A24)}$$

where QH_i is the consumption of commodity i of households, mpc is the marginal propensity to consume of the household, γi is the share of commodity i in the household' consumption expenditure, and *th* is the income tax rate. Adding transfer payments of households to the rest of the world (THW) and to the government (THG) on consumption expenditure will give the total household expenditure as follows:

$$EH = \sum_i PQ_i \cdot QH_i + \text{THW} + \text{THG} \quad \text{(A25)}$$

where EH is the total household expenditures. Household saving is disposable income minus total household expenditures:

$$HSAV = DI - EH \quad \text{(A26)}$$

where DI is disposable income and HSAV is household saving.

A.4 Modeling the government

The government revenues include tax revenues, import duties, capital revenues and transfers from other economic agents.

$$YG = \sum_i [tm_i \cdot QM_i \cdot \overline{PMW}_i \cdot EXR + tx_i \cdot QQ_i \cdot PQ_i] + tki \cdot \sum_i QKD_i \cdot pk_i + tli \cdot \sum_i wl_i \cdot QKL_i + \text{THG} + \text{TWG} \quad \text{(A27)}$$

where YG is the government revenues; tm_i, tx_i, tk_i and tl_i are rates of import duty, excise tax, capital tax and labour tax respectively. TWG is transfers from rest of world to the government. The government's expenditure includes commodity consumption, energy subsidy, transfer payments to households and foreign entities:

$$EG = \sum_i PQ_i \cdot QG_i + s_e \cdot \sum_i PQ_{e,i} \cdot QQ_{e,i} + TGH + TGW) \quad \text{(A28)}$$

where EG is government expenditure, TGH and TGW are the government's transfer payments to households and foreign countries, respectively, s_e is rate of subsidy for electricity. Subscript e,i refers to electricity commodity consumed by sector i. In the equation above, the government consumption demand is given by:

$$PQ_i \cdot QG_i = shrg_i \cdot mpcg \cdot YG \quad \text{(A29)}$$

where $shrg_i$ is the share of commodity i in the total government's consumption and $mpcg$ is the government's marginal propensity to consume. Accordingly, the government saving (GSAV) is:

$$GSAV = YG - EG \quad \text{(A30)}$$

A.5 Market clearing and macroeconomic closure

Closing rule for the non-energy commodity market is:

$$QQ_i = \sum_j ica_{i,j} \cdot QINTA_j + QH_i + QG_i + QINV_i, i \in NE \quad \text{(A31)}$$

where $QINV_i$ is the demands for commodities i used as investment. For energy commodities, the closing rule is:

$$QQ_i = \sum_j QE_{i,j} + QH_i + QG_i + QINV_i,\ i \in E \quad \text{(A32)}$$

Where $QE_{i,j}$ is the inputs of different energy commodities of every industry, where *i* refers to two kinds of energy commodities, i.e. electricity and petroleum products.

Factor market clears based on the equality between factor demand and factor supply, implying full employment. Thus, the following two equations govern factor market clearing in the model.

$$\overline{QLS} = \sum_i QLD_i \quad \text{(A33)}$$

$$\overline{QKS} = \sum_i QKD_i \quad \text{(A34)}$$

This model is a savings-driven model in which the total investment is determined by the total savings as follows:

$$TOTINV = HSAV + GSAV + EXR \cdot FSAV + WALRAS \qquad \text{(A35)}$$

$$PQ_i \cdot QINV_i = shareinv_i \cdot TOTINV \qquad \text{(A36)}$$

where $TOTINV$ is the total investment, $FSAV$ is foreign savings, $WALRAS$ is dummy variable, and $shareinv_i$ is the share of commodity i used as investment in the total investment.

The difference value of income and expenditure of foreign countries is foreign savings and given as:

$$\sum_i PWM_i \cdot QM_i + sharewl \cdot \sum_i WL \cdot QLD_i / EXR + TGW = \sum_i PWE_i \cdot QE_i + TWH + FSAV \qquad \text{(A37)}$$

where $sharewl$ is the foreign countries' share in total labour payment.

The real GDP is calculated using the expenditure approach as follows:

$$GDP = \sum_i (QH_i + QG_i + \mathrm{QINV}_i) + \sum_i QE_i - \sum_i QM_i \qquad \text{(A38)}$$