Exploring Carbon Pricing in Developing Countries

A Macroeconomic Analysis in Ethiopia

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Context and objective
In response to a challenge from members of the Carbon Pricing Panel for the world to expand carbon pricing to cover 25 percent of global emissions by 2020, Ethiopia commissioned a carbon pricing study to obtain recommendations on the role and possible forms of carbon pricing policies in Ethiopia. The study summarized in this report is a collaborative effort by the Government of Ethiopia, the Ethiopian Development Research Institute (EDRI), and the World Bank to better understand the potential benefits and costs for Ethiopia with use of carbon pricing to reduce greenhouse gas (GHG) emissions. The study also investigates distributional impacts of carbon pricing and measures that can help address unwanted distributional impacts. The specific aims include supporting the Government of Ethiopia (GoE) in identifying policy actions, including carbon pricing, to achieve its GHG emission reduction targets; facilitating a dialogue among Ethiopian stakeholders on related policy instruments; and building analytical and technical capacity for GoE's future policy planning. Lessons from this analysis may also be useful for other low-income countries.

Economic structure and emissions
Sources of carbon emissions can be determined by the structure of a country's economy and its energy mix. For several decades, the Ethiopian economy has been largely agriculture-based. The last two decades, however, have witnessed a structural shift away from the agriculture sector towards the service sector, while the share of industry remains low. The main source of electricity in the country has been hydropower, with recent additions from thermal and wind sources. But access to electricity is still limited to urban areas, and biomass burning is the main source of energy for rural households. Accordingly, **livestock accounts for the largest share of the national GHG emissions** (54.5 percent). **Land use and forest change, including unsustainable harvesting of fuelwood, represent the second largest share** (38.46 percent). Petroleum fuels and kerosene, on the other hand, account for a much smaller share of emissions with 4.5 percent and 1.8 percent respectively (see Figure 3.1).

Methodology
To assess the various impacts of carbon pricing, we use a computable general equilibrium (CGE) model to analyze various **policy scenarios** that specify which sources of carbon emissions to tax, the tax rate, and what is done with the revenue generated through the carbon tax. In this study, we focus on scenarios that put a price on GHG emissions from petroleum fuels and kerosene, even though their shares of total GHG emissions are relatively small. This is because the emissions in question are easy to measure and get taxed through taxes on the energy sources themselves, based on the amounts of GHG emitted per unit of energy. In addition, petroleum fuels are consumed disproportionately by higher-income groups.

In terms of carbon prices, we analyze the implication of a price that starts at \$5 per ton of CO_2 in 2018 and rises to \$30 per ton in 2030. Previous research highlights that the economic impacts of a carbon tax depend significantly on what is done with the revenue, i.e. "recycling" revenue by cutting other taxes can soften negative effects of the tax on overall economic activity and on the distribution of income. Accordingly, we study the differences in impacts of the carbon tax with revenue recycling through a uniform sales tax reduction, reduction of labor income tax, reduction of business income tax, direct transfer back to households, and use by government to reduce debt.

General results

- Imposing a carbon price on fuels has a small impact on the economy. With a carbon tax, GDP in 2030 is only 0.7 percent to 1.6 percent lower than the base case, depending on the scenario. Using the carbon tax revenues to cut sales tax or business income tax leads to a smaller impact on GDP compared to the other scenarios. Both of those tax cuts reduce distortions in the economy, which encourages investment.

- GHG emissions are lower than in the baseline under all policy scenarios. The size of the GHG emissions reduction reflects the pattern of GDP impacts. Because economic activity is larger when carbon tax revenues are recycled by cutting sales or business income tax, compared to other scenarios, GHG reductions are not as large with those tax cuts compared to other options. For instance, the annual emission reduction in 2030 is 1.7 million tons in the sales tax reduction scenario, whereas the reduction is 3.8 million tons in the labor income tax reduction scenario.

- Significant revenue can be raised from a carbon tax. The government can, in turn, use portions of that revenue to reduce other taxes, as a source of income transfers to lower income households, or for other public purposes. Approximately, GHG emissions from fossil fuels in Ethiopia were 9.54 million tons in 2015. This implies that, in 2015, a $5 per ton price on emissions, based on the carbon content of fuels, would have raised $47.7 million and a $30 price on carbon would have raised $286 million. In our policy scenarios, with the price on carbon rising to $30/ton in 2030, total revenue from the carbon tax can be as high as $800 million in that year, depending on the scenario.

Distributional implications

Households are employed in different sectors; therefore, the distributional consequence of the carbon tax on fuels depends on the importance of those fuels in different sectors. As industry and service sectors are more transport-intensive and therefore more fuel-intensive, a carbon tax has a larger proportionate effect on them. Since most urban households receive a large proportion of their income through employment in the service and industrial sectors, **a carbon tax tends to affect income and consumption of urban households more than rural households** (see Figures 4.4 and 4.5). However, the impacts also depend on the consequences of the revenue recycling mechanism. Reduction in sales tax or business income tax increases employment of low-skilled individuals or the wage rate of high-skill individuals respectively, compared to other scenarios. Consequently, the economic impacts on lower-income individuals are lower under these revenue recycling options, compared to other scenarios.

Caveats and topics for further investigation

The CGE model used in this study for evaluating different policy options is very much representative of current practice for this kind of analysis. Nevertheless, there are some important limitations of the model for capturing fully the impacts of a carbon tax. The model does not explicitly differentiate between employment and output from informal and formal sectors of the economy, and it does not include the possibility of lasting structural unemployment for part of the labor force. Relaxing those limitations with a more advanced CGE model would likely lead to even smaller adverse effects on output and employment of a carbon tax, or potentially even net gains, along with reduced evasion of taxation within the informal sector. Further investigation of these points would represent a valuable direction for follow-up work.

As noted, GHG emissions from fossil fuel combustion are only part of the story. Other significant emissions sources include land clearing for expanding agriculture, and unsustainable consumption of wood-based fuels for cooking and heating. To provide a complete picture of how carbon pricing and other policies can manage Ethiopia's emissions in accordance with its national commitments, it is necessary to go beyond the scope of this study to consider **what combinations of pricing and other measures can be effective in limiting emissions from the agriculture and forest sectors, including**

fuelwood in the latter. Using price-based measures to restrict land clearing and fuelwood use is challenging; however, several promising ideas are beginning to emerge in recent studies. Other possibilities include expanding both current reforestation programs and current clean cooking programs that reduce fuelwood demand through more efficient wood fuel cookstoves and through fuel-switching, especially in urban areas. Both reforestation and clean cooking initiatives can provide large co-benefits through increased ecosystem protection, and improved health by reducing air pollution exposure. Revenues from a carbon tax could be used in various ways to support such initiatives. Beyond researching efficient expansion of reforestation and clean cooking measures, another fruitful avenue for investigation is how changes in current industrial and trade policies could expand access to more energy-efficient and less-polluting technology and capital. Further analysis that considers a broader range of economic instruments to mitigate emissions from land-use and land-use change is recommended. This includes: (i) land tax or subsidies that encourage land rehabilitation, reforestation, maintenance of natural forests; (ii) payments for environmental services; and (iii) land clearing taxes.

1 Introduction

As part of the Paris Agreement at the 2015 Conference of Parties to the UN Framework Convention on Climate Change, most countries have established Nationally Determined Contributions (NDCs) that lay out their intended actions to limit GHGs in the spirit of the common but differentiated responsibilities and respective capabilities. Countries have identified what they aim to achieve in terms of reducing emissions against a baseline, through reducing emission and energy intensity and increasing penetration of renewable energy. The challenge is to implement these actions. What instruments need to be used for implementation, including what role carbon pricing can play in the broader framework of enabling policies that countries adopt, is one of the key issues. Carbon pricing can be an effective tool for establishing incentives for mitigation action, mainly for fossil fuel emissions. Indeed, NDCs of more than 90 countries refer to carbon pricing in one form or the other (NCE, 2016). So far, carbon pricing has been applied almost exclusively in high- and middle-income countries; the impact of mitigation policies and carbon pricing on low-income countries is less understood.

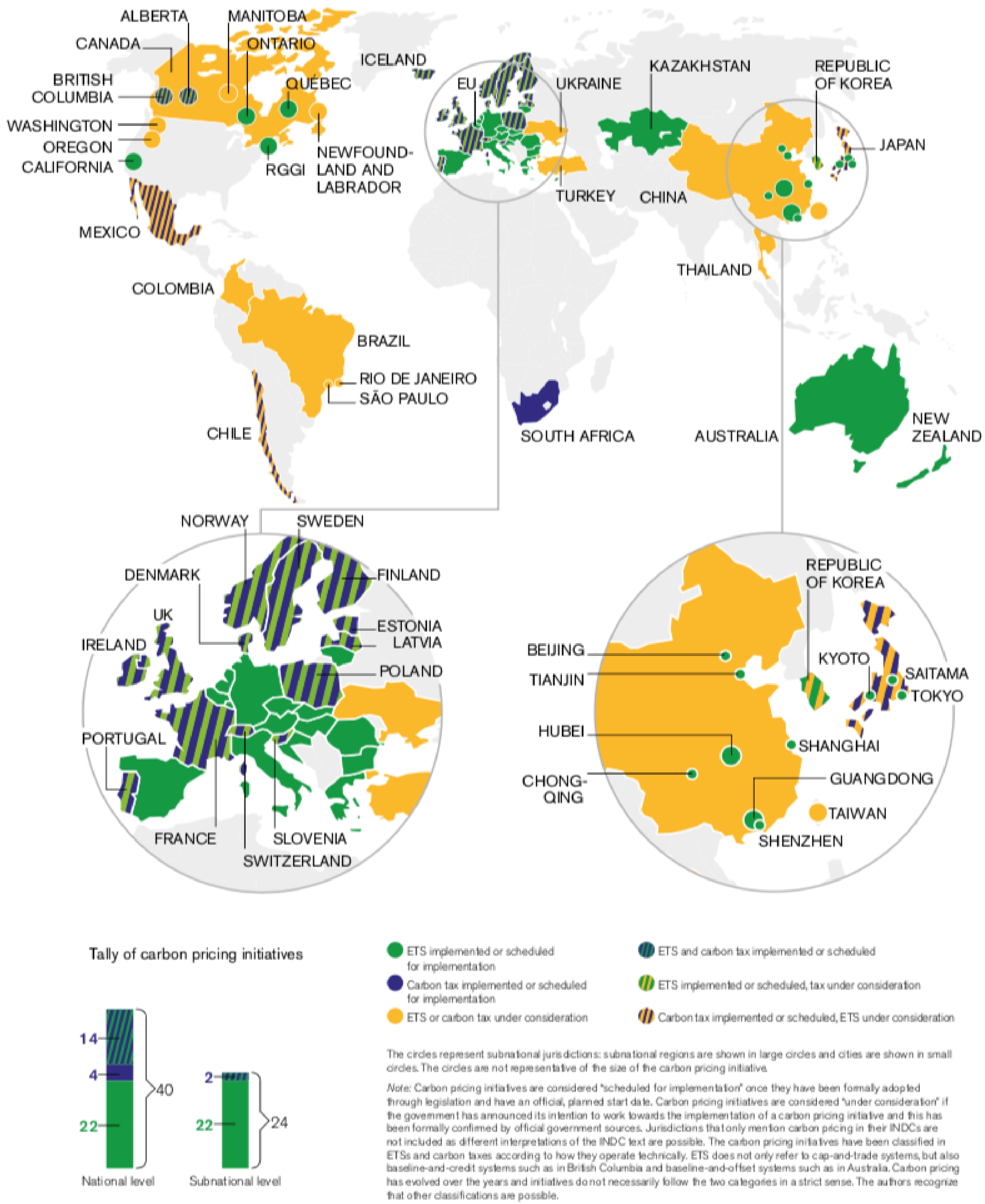
In addition to limiting GHG emissions, predictable and consistent carbon pricing over a long-term time horizon can yield other benefits. There is a potential to reduce air pollution by discouraging use of low-efficiency and high-emitting boilers in manufacturing and power sectors, as well as by encouraging use of more modern vehicles that are higher-efficiency and less-polluting. Carbon pricing in the form of tax can also raise considerable revenue which can result in reductions of other taxes, income transfers to help the poor, or public investments that increase economic and environmental well-being. For example, Winkler (2017) shows how carbon tax revenues can be used to promote sustainable energy production in South Africa; of the tens of billions of dollars in carbon tax revenues already being raised, more than a quarter is going to green spending (Carl and Fedor, 2016). Carbon taxes are also relatively easy to implement, and less prone to problems of tax evasion than other forms of taxes (Lui, 2013; High-Level Commission on Carbon Prices, 2017). Moreover, experience from recent fossil fuel subsidy reforms in some developing countries shows that governments can mitigate potential negative impacts of carbon taxes on the poor (Ruggeri Laderchi, 2014).

1.1 Historical Development of Carbon Pricing

Over the last decade, carbon pricing initiatives have spread across the world. As of 2017, 42 national and 25 subnational jurisdictions have implemented or plan to implement carbon pricing in the form of carbon taxes or emissions trading systems (ETS), as shown in Figure 1 (World Bank, Ecofys and Vivid Economics, 2017). The growing scope and coverage of carbon pricing schemes provides a wealth of knowledge and experience on possible appropriate design, implementation and building acceptance for the domestic carbon pricing instruments in high- and middle-income countries.

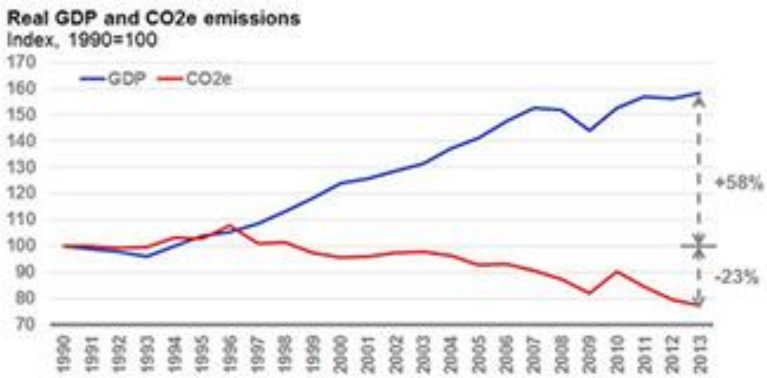
Carbon taxes adopted by several Balkan and Scandinavian countries in the early 1990s continue to be used. Sweden currently has the highest carbon tax in the world, at USD 131/tCO_2. The country has kept high carbon taxes for almost three decades now, while at the same time expanding its economy by close to 60 percent and reducing its carbon emissions by more than 20 percent (Figure 1.2). Carbon prices in most countries and regions are, however, still very low (World Bank, Ecofys and Vivid Economics, 2017).

Figure 1.1: Summary map of existing, emerging and potential regional, national and subnational carbon pricing initiatives



Source: World Bank, Ecofys and Vivid Economics 2017. State and Trends of Carbon Pricing 2017. World Bank, Washington, DC.

Figure 1.2: Real GDP and CO2e Emissions in Sweden 1990 - 2013



Sources: Swedish Environmental Protection Agency, Statistics Sweden

1.2 Ethiopia's Engagement with Carbon Pricing

In April 2016, members of the Carbon Pricing Panel, including heads of state and the heads of the World Bank and International Monetary Fund, challenged the world to expand carbon pricing to cover 25 percent of global emissions by 2020–double the current level–and to achieve 50 percent coverage within the next decade. As part of its national policy to build a climate resilient green middle-income economy, Ethiopia declared its ambitious contribution of reducing its emissions by 64 percent by 2030 from business as usual (BAU). Ethiopia expressed interest in the use and promotion of all policy instruments and public investment schemes, including carbon pricing, that have been found to be effective, fair, and efficient in preventing dangerous climate change. To deliver on this commitment, and as a response to the Carbon Pricing Panel, Ethiopia commissioned a carbon pricing study to obtain recommendations on the role and possible forms of carbon pricing policies in Ethiopia, which might also be applicable to similar low-income developing countries.

1.3 Study Objectives

The study summarized in this report is a collaborative effort among between the Government of Ethiopia, Ethiopian Development Research Institute (EDRI), and the World Bank. Its aim is to support the Government of Ethiopia (GoE) in an ongoing effort to identify policy actions, including carbon pricing, to achieve its GHG emission reduction targets across sectors, while mitigating economic and social impacts. To that end, the study is designed to better understand the potential benefits and potential costs to the economy as a whole associated with carbon pricing. The study also investigates potential distributional impacts of carbon pricing, and measures that can help address unwanted distributional impacts. The collaborative approach to the study, with a lead analytical role played by EDRI, strengthens analytical and technical capacity for GoE's future policy planning, including the use of qualitative and quantitative policy assessment methods.

2 Ethiopia's Climate Policy Context

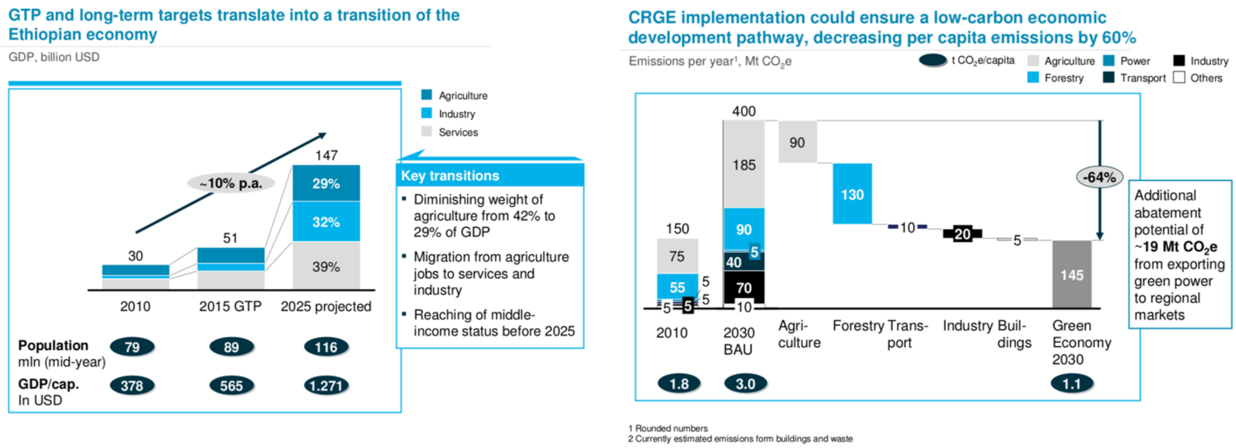
Ethiopia is vulnerable to the adverse impacts of climate change and the unpredictability of climate variability due to its low adaptive capacity, limited livelihood options for most of the population, climate sensitive sectors (such as agriculture and energy), and land prone to degradation and desertification, among others. Rainfall is highly erratic and typically falls in the form of intensive convective storms spawned by the country's varied topography. Over the past three decades, Ethiopia has experienced countless localized drought events and seven major droughts, five of which were associated with famines. Future climate variability and change are expected to accelerate already high levels of land degradation and soil erosion, increase vulnerability to droughts and floods, and negatively impact agricultural productivity.

The GoE has taken concrete actions to better manage adverse impacts and risks of climate change and variability and has made major progress in advancing its climate agenda. Already, starting in the aftermath of the 1984 drought and famine, the country has, over the past three decades, implemented successive policies and programs intended to rehabilitate degraded lands and build the adaptive capacity of drought-prone regions. For example, since 2005, the country has implemented a national program called 'Managing Environmental Resources to Enable Transitions (MERET)'. MERET adopted a community-based watershed planning approach to address the root causes of vulnerability and food insecurity through community-driven rehabilitation, including soil and water conservation, afforestation and water harvesting. The MERET program therefore followed a 'triple win' approach of enhancing resilience, climate mitigation potential (e.g., through increased forest cover), and productivity of rural landscapes (Haileselassie *et al*., 2009; Gebreegziabher *et al*., 2016). Another example is the ongoing Sustainable Land Management Program (SLMP).

The successful experiences in building resilience via programs like MERET and SLMP which have made Ethiopia a recognized leader on climate action and landscape restoration, are being complemented by GHG mitigation policies. Over the past decade, the government has prioritized low-carbon growth and poverty reduction, as well as climate resilience. For example, fossil fuel subsidies have been removed, with both economic benefits and limited social impacts, since studies show that fossil fuel subsidies benefit mainly the richer segments of the population.

Ethiopia demonstrated a strong political will and readiness to act on climate change by laying out ambitious climate commitments as part of its NDC and through its Climate Resilient Green Economy (CRGE) Strategy (FDRE,2011), which seeks to protect the country from the adverse effects of climate change while building a green economy that will help realize its ambition of reaching middle-income status by 2025. As stated in the Strategy, the country aims to limit its net annual greenhouse gas (GHG) emissions in 2030 to 145 Mt CO2e or lower, which would constitute a 255 Mt CO2e (64 percent) reduction from the projected BAU emissions (400 Mt CO2e) by focusing on seven key sectors: livestock, crops, forest, energy, buildings, industry, and transport. In financial terms, Ethiopia has estimated an investment of USD 7.5 billion annually until 2030 on initiatives that will contribute to economic advancement and emission reductions. In this regard, the government has already set up a national financial mechanism called the Ethiopia CRGE Facility, managed by the Ministry of Finance (MoF) and the Environment, Forests and Climate Change Commission.

Figure 2.1: The CRGE Strategy



Source: FDRE, 2011

Ethiopia has mainstreamed the CRGE Strategy into its Second Growth and Transformation Plan (GTP II) (FDRE,2015) that covers the period 2015/16-2019/20. The GTP II also articulates integrated approaches for optimal land and water use and sustainable resource management to create resilient rural landscapes. This integrated approach builds on the successes in the agricultural and forestry sectors achieved during the first Growth and Transformation Plan (GTP I, 2010/11—2014/15)(FDRE 2010), which is instrumental in realizing GTP II targets. This ensures that the CRGE initiative is part of a comprehensive national plan for public investments as well as the legal and institutional reforms necessary to create an enabling environment for wider stakeholders, including private sector and community engagement. Ethiopia, in collaboration with development partners, is also implementing national flagship projects (such as the Agricultural Growth Program and the Resilient Landscapes and Livelihoods Project) and preparing projects (such as the Rural Productive Safety Net Project, and Renewable Energy Guarantees Project) that are designed to enhance climate resilience as well as provide tangible economic benefits.

3 The Structure of the Ethiopian Economy and its Carbon Emissions

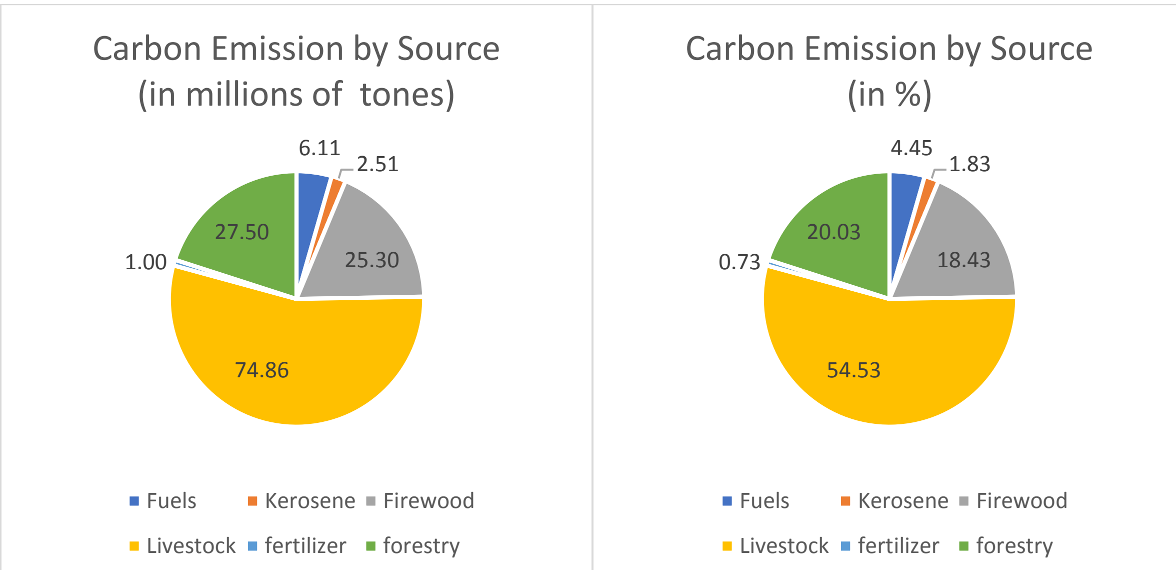
The Ethiopian economy has been largely agricultural for several decades. The last two decades, however, witnessed a structural shift away from the agriculture sector (See Table A.1. in the Appendix). While most of the shift in the first decade has been towards the service sector, the latter decade has seen substantial growth in the industry sector’s share of the economy. This has been stimulated by an ever-expanding construction subsector.

Before analyzing the impact of carbon taxation on the economy, the sources of carbon emission in the country and their direct and indirect uses by economic activity and household are examined in the next subsection. This will provide a reference framework for the carbon taxation simulation.

3.1 Carbon Emission by Source[1]

The vast majority of carbon emission emanates from the agriculture sector, land-use change and forestry, as shown in Figure 3.1. Most of the emissions from the agriculture sector come from livestock. This includes enteric fermentation, manure left on pasture, and manure applied on soil. Emissions from land-use change and forestry include emission due to forest clearance and land-use conversion for small holder agricultural expansion, promotion of large- scale agriculture, human settlement and authorized and unauthorized logging. Emissions from unsustainable extraction of fuelwood also are typically included within forestry; however, in the subsequent analysis, fuelwood will be considered separately.

Figure 3.1: The sources of carbon emission in Ethiopia



Source: The livestock and fertilizer data are sourced from FAO (www.fao.org/faostat/en/#data/GT, 2017a. The forestry and firewood data are from the Environment, Forests and Climate Change Commission (MEFCC) (Mefcc.gov.et/Ethiopia-forest-sector-ghg-emissions, 2017). The data on fuels and kerosene are from the International Energy Agency (IEA) (https://www.iea.org/statistics/statisticssearch/report/?country=Ethiopia&product=oil, 2015). Emission factors are from FAO (http://www.fao.org/faostat/en/#data, 2017b), and Intergovernmental Panel on Climate Change (IPCC) (http://www.ipcc-nggip.iges.or.jp/public/2006gl/vol4.html, 2017).

Figure 3.1 shows that livestock accounts for 74.86 million tones (54.53 percent of total emissions), and forestry and firewood together emit 52.8 tons of carbon (38.46 percent of total carbon emissions), respectively. In contrast, the use of petroleum (fuel and kerosene) accounts for only 6.28 percent (i.e., 8.62 million tons of carbon) of overall emissions. Emissions from fertilizer use in the agriculture sector are based on 650,000 tons of fertilizer used in 2012 (Rashid et al, 2013).

Each of the carbon emission sources mentioned above result from either direct consumption by households or use of intermediate inputs in the production of other goods and services. Using statistics on total outputs and inputs of different sectors in the Ethiopian economy, we can compute the direct and indirect carbon intensities and emissions shown in Table 3.1 that result from the different sources of carbon emissions[2]. Table 3.1 shows that firewood, coal, and livestock have respectively the highest carbon

[2] The mathematical formula used to arrive at the figures presented in Table 3.1 is given in Appendix C.

intensity as measured by tons per million birr of final demand. Kerosene, petrol and fertilizer are a second set of product groups with significant carbon intensity.

Table 3.1: Carbon Intensity by Group of Products

Product group	Carbon intensity (tone of CO_2) per millions of birr of final demand
Crops and vegetables	21.7328
Livestock	1231.5690
Forestry	15.8061
Firewood	1937.6923
Fishery	9.6860
Coal	1725.8067
Other mining	6.4570
Food processing	183.0464
Textile and leather	43.9511
Wood and paper products	2.6070
Fuels (petroleum other than Kerosene)	196.6678
Kerosene	262.0189
Chemicals	7.3888
Fertilizer	183.9924
Non-metal minerals	23.8183
Metals and metal products	20.5485
Machinery and Equipment	2.1693
Vehicles	2.3315
Other manufacturing	4.3117
Electricity	33.4582
Water	36.4595
Construction and real estate	12.4329
Trade	2.7021
Transport	47.5188
Hotel	106.0756
Communication	11.4304
Financial and business services	0.6253
Public administration, education, health, and other services	12.6620

Source: Authors' calculation based on the 2010/11 Ethiopian Social Accounting Matrix

The incidence of carbon price on households depends on the carbon content of their consumption, among other factors. Figure 3.2 describes the carbon emission due to indirect consumption of petroleum fuels, not including kerosene. Petroleum fuels consumption and the resulting emissions are higher as a proportion of a given consumption for richer and urban households. However, the pattern becomes less clear if we consider the consumption of kerosene (Figure 3.3). Because urban households tend to be more dependent on modern transport, they are more intensive consumers of petroleum fuels. They utilize electricity in addition to kerosene for cooking and lighting purposes. Rural households, on the other hand, lack adequate access to electricity. As a result, they rely more on kerosene for lighting and cooking purposes. The overall fuel (petroleum and kerosene) intensity of consumption of households tends to be similar across categories of households.

3.2 Benchmarking Ethiopia's GHG Emissions in the African Context

In the larger global context, GHG emissions in all Sub-Saharan Africa remain small in both absolute and per-capita terms. The main reason is the overall low level of economic development, and a relatively low level of energy consumption resulting from lack of access to formal energy sources. This is why agriculture and land-use change and forestry (LUCF) play a disproportionately large role in the emissions profile.

Fig. 3.4 shows countries based on their population size, per capita income and per capita GHG emissions level. Per capita emission is low overall with a few exceptions such as Botswana, South Africa, and Equatorial Guinea, which are countries with higher economic growth and much lower population. But most countries are well below lower middle-income status. Low per capita GDP invariably translates to low level of emissions.

Energy consumption in Africa is highly inefficient overall with respect to the global average. Energy poverty is a recurring theme in most countries, as reflected in both low access to electricity and the high share of informal biomass in the total primary energy mix.

Future economic growth will be accompanied by growing energy use. Policymakers need to concern themselves with where economies will be and not where they currently are. The lower the level of development, the more important become questions around climate resilience (especially of agriculture) and adaptation. Most countries in the region are populous and fast-growing economies. The steps taken by major Sub-Saharan African economies such as Ethiopia can serve as yardsticks by which climate policy efforts of other countries will be measured. In that context, carbon pricing can be a tool to help point future energy use in the right direction as countries grow, with investment in energy efficiency and expanded access to low-carbon energy as well as measures for sustainable land and forest management. As the Ethiopian economy rapidly expands, it is recommended that the country not lock itself into inefficient energy and infrastructure investments as they are difficult to reverse. The relative costs of energy alternatives are changing quickly in favor of renewables. Investing in technology that is projected to be lower cost in the future will be a comparative advantage to the newly industrialized economy.

Figure 3.2: Carbon intensity of household consumption due to petroleum

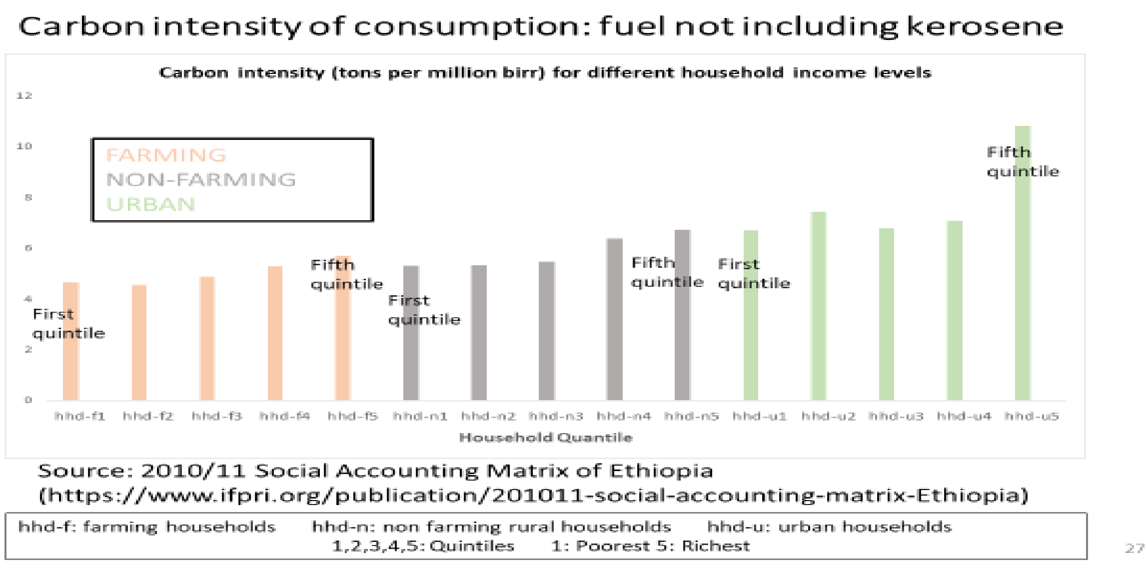
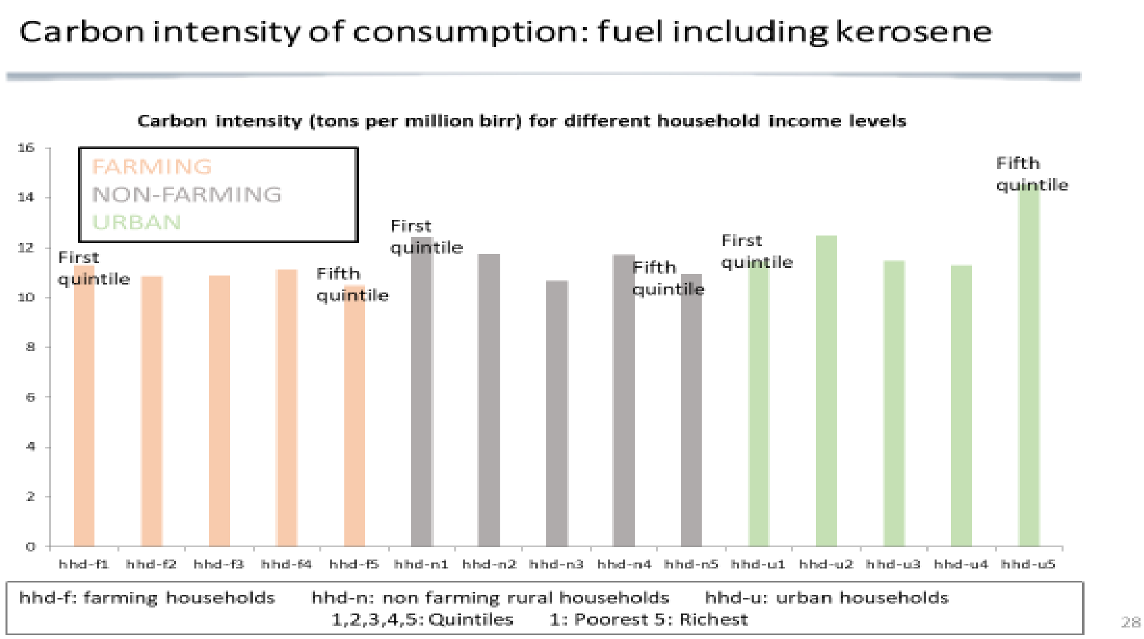
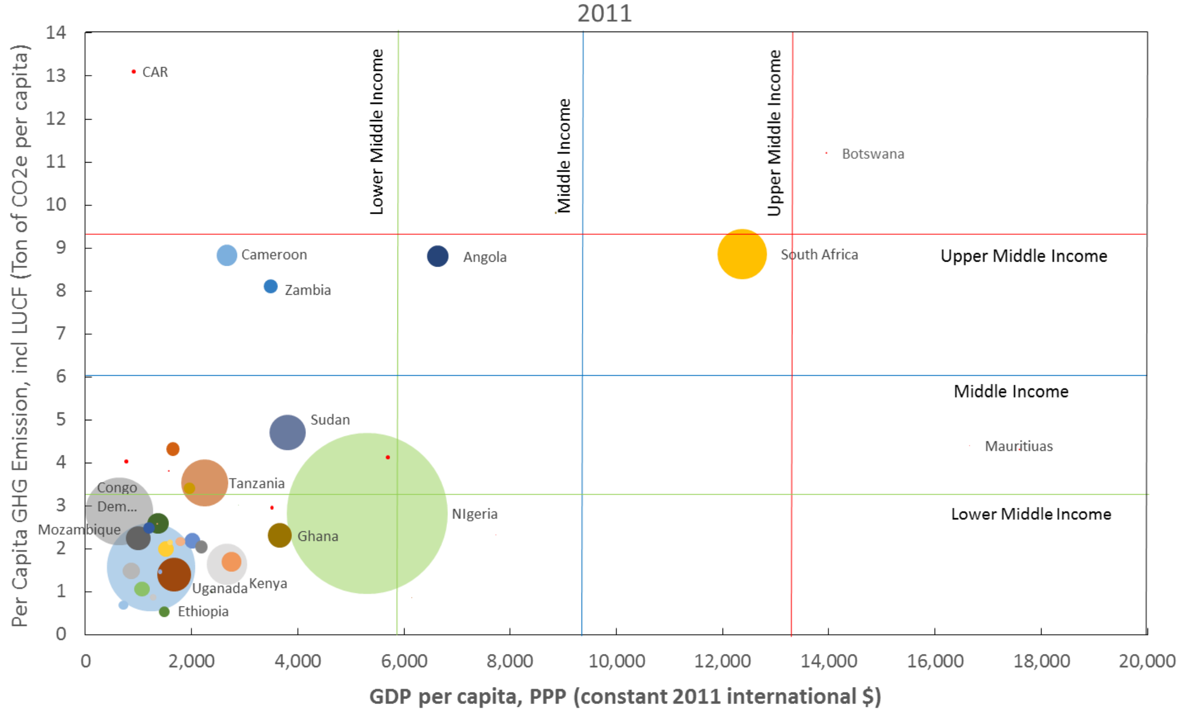


Figure 3.3: Carbon intensity of household consumption due to petroleum and kerosene



Source: Authors' calculation based on the 2010/11 Ethiopian Social Accounting Matrix

Figure 3.3: Benchmarking GHG emission with respect to the economy



Note: Equatorial Guinea and Seychelles are not included as their high level of per capita emissions distort the chart
Source: World Bank World Development Indicators Database (http://wdi.worldbank.org/tables), WRI CAIT Database (https://www.wri.org/resources/websites/cait).

4 Methodology for Assessing the Impacts of Carbon Pricing in Ethiopia

4.1 Modeling Framework

This study relies on a recursive dynamic Computable General Equilibrium (CGE) model. It is an extension of the Computable CGE model developed by the International Food Policy Research Institute (IFPRI). The model is formulated as a set of simultaneous linear and non-linear equations that simulate the behavior of consumers and producers across the economy, as well as the functioning of the economy in which these agents operate.[3] The model can be used to assess the impacts of carbon pricing by tracking, in detail, various transmission mechanisms within and across sectors. The model describes market equilibrium conditions, macroeconomic balances, and dynamic updating equations. Given the nature of our input data, we run all the model scenarios over a period starting in 2018 and ending in 2030.

4.2 Baseline Scenario

Analyzing the impacts of a carbon tax requires a comparison of the performance of the economy with the carbon tax vis-à-vis a Business-As-usual (BAU) case without the tax. Our baseline scenario is based on the growth plan embedded in GTP II (FDRE, 2015). We assume that the investment programs, tax policy, and environmental policies in GTP II will take place. This includes all environmental polices embedded in the

[3] More details about the model are included in Appendix A.

CRGE (FDRE, 2011) Strategy. The economic growth under the BAU scenario that we utilize is recorded in the first two years of the GTP II period (i.e., a GDP growth rate of 7.6 percent).

4.3 Policy Scenarios

The policy scenarios included in the current study differ from the BAU not only due to the imposition of a carbon tax but also due to a set of decisions regarding (i) what sources of carbon to tax, (ii) the time path of carbon prices, and (iii) how to use money that is raised through the carbon tax. Decisions taken on each of these elements will imply different policy impacts on the economy vis-à-vis the baseline.

4.3.1 What sources of carbon to tax?

As shown in Fig. 3.1, most of the carbon emission in the country comes from the agriculture sector. This implies that any tax that will put a significant dent on emission would have to address the agriculture sector. However, there are two reasons why this would be undesirable and difficult to implement. The sources of emissions from agriculture and forest land-use are diverse and diffuse. This makes these sources difficult to tax without extensive, costly, and untested measurement, reporting, and verification (MRV). Note that imposing a carbon tax merely on agricultural and forest outputs is not possible because the carbon intensity of outputs may substantially differ across suppliers and regions of the country. In addition, most of the agricultural activity in the country is undertaken by smallholder farmers engaged in subsistence agriculture. Burdening them with a carbon tax, even if it could be figured out how to do so, would have adverse distributional consequences.

In contrast, taxing fossil fuels has the inverse pros and cons of taxing agricultural emissions. It can easily be administered by imposing a tax on fuel importers. In other words, it does not involve significant levels of MRV measures. Moreover, it is an effective approach for taxing the informal sector. In addition, it can easily be linked with other existing taxes in the overall fiscal system. Thus, although fossil fuels make only a small contribution to total GHG emissions in Ethiopia (a bit more than 6 percent, as noted in Section 3), this study focuses on putting a price on the carbon emitted from fossil fuels. An important follow-up task beyond the scope of this study is to give much deeper consideration to what policies, beyond carbon pricing, can effectively mitigate GHG emissions from agriculture and forestry.

How kerosene is factored in carbon tax analysis has important implications due to two seemingly countervailing reasons. On the one hand, kerosene is an alternative cooking energy to fuelwood; taxing it may backfire by increasing consumption of fuelwood which could result in more GHG emissions as well as worse indoor air pollution. On the other hand, exempting kerosene from a carbon tax could lead to tax evasion through reclassification of other fuels as kerosene. We have carried out our policy comparisons both with and without kerosene. However, in this report, we include only results from the analysis with kerosene taxed. The results with kerosene exempted are available on request.

4.3.2 The time path of carbon prices

Another important factor is deciding what level of tax to impose and how the tax rate evolves over time. Consistent with experiences of other countries (World Bank, Ecofys and Vivid Economics, 2017), we have analyzed three possible cases.[4] The first entails imposing a low tax of about $5 per ton throughout the time period of the analysis (2018-2030). The second entails imposing a higher tax rate of $30 per ton initially and maintaining that rate throughout 2018-2030. In the third case, the tax rate starts at $5 per ton and then steadily grows over the study period until it reaches $30 per ton in 2030. Although we have run our model based on all three tax design cases, in this report, we include only the results from the third

[4] Although the range of carbon prices as of 2017 range between $1 per ton to $140 per ton, the most common is in the range of $10 to $40 per ton.

case “starting low and steady growth” for various reasons: (i) it is a realistic assumption of how carbon pricing might be implemented in practice; (ii) a carbon price of $5 per ton has little relevance by 2030 when countries’ NDCs targets need to be met; and (iii) a carbon price of $30 per ton now can be considered excessive if compared with other developing economies.

While the carbon price is to function as a tax on carbon emissions, in practice it needs to be imposed on the fossil fuels themselves; therefore, it is necessary to convert the carbon tax rate to fuel-specific taxes based on their respective carbon contents. Imposing a $5 price on carbon is equivalent to a 2.23 percent tax on petroleum fuels, based on the fuel prices utilized in the study.[5] Similarly, a $30 price on carbon is equivalent to a 13.4 percent tax on petroleum fuels given the assumed prices.

As of 2015, 2.68 million tons of various oils were used in the country(IEA, 2015). Using the average conversion factor of 3.5 tons of CO_2 per ton of oil, the CO_2 emissions in 2015 from use of fossil fuels was 9.54 million tons. Consequently, in 2015, a $5 price on carbon would have raised $47.7 million, while a $30 price on carbon would have raised $286 million.

5 How to use the increased carbon revenue

The structure of the model we employ is such that the equilibrium in the economy is consistent with the government budget constraint. The revenue from carbon tax increases government revenue. The government has to use the money to reduce borrowing, reduce debt, increase spending, or reduce other taxes. Consequently, how to utilize the increased government revenue becomes a relevant policy issue. After discussions with many policy-making units and other relevant stakeholders, we decided to evaluate five options for how to use the money that is raised through the carbon tax:

1. **STAX-** a scenario where we adopt uniform reduction of sales taxes for intermediate and final commodities.
2. **TRANS-** a scenario where the increased government revenue is used as a lump-sum transfer payment to all households. Lump sum transfer payments follow the same pattern of existing allocation of government transfers to each type of household. The proportion of transfers to household types is maintained[6].
3. **SAVINGS-** a scenario where the money from carbon tax is directed to the overall saving pool where it can then be invested in most profitable sectors.
4. **DTAX-** a scenario where the money from carbon tax is transferred to taxpaying households in the formal sector. This is done in the form of uniform reduction of direct taxes (personal income tax).
5. **CORPOR-** a scenario where the money is used to encourage investment by firms. This is achieved by uniform reduction of business income tax.

We compare the results from imposing the specified carbon tax with these different uses of revenues to the BAU scenario.

[5] $5 per ton of co2* 3.5 ton of co2 per ton of fuel = $17.5 per ton of fuel. Since 1,176 liter is equal to 1 ton of oil, this is equivalent to $0.015 per liter of fuel. Using the current price of $0.67 /liter of fuel, then $5 price is equivalent to 2.23 % tax.

[6] As indicated in the appendix, the Social Accounting Matrix has 15 types of households. The initial share refers to the government transfer to each type of household relative to over all government transfer to households. The basic premise in this scenario is that the current transfer scheme reflects the weight the government puts on the welfare of each type of household.

6 Modeling Results

6.1 Impact on emissions

Figures 6.1 and 6.2 present summary results of changes in emissions across the different scenarios. The figures show that, as expected, emission reductions increase over time as the price on carbon increases. Depending on the recycling scenario, the reduction ranges from 1.1 million tons to 1.5 million tons relative to BAU in 2030, when the carbon tax reaches its maximum value. The differences across scenarios are due to the differences in growth of the economy due to the different revenue recycling mechanisms considered, which in turn influence the demands for fossil fuels.

Comparing across the scenarios, the least emission reduction is achieved in the sales tax (STAX) reduction scenario. This is because its effect on the general economy results in the least growth impact (Figs 6.1 and 6.2 below). Direct tax reduction (DTAX), on the other hand, leads to more significant reductions in emissions.

Similar comparisons follow when we compare the resulting reductions in emissions from all emission sources. These will be larger than the reductions in emissions in fossil fuels, because the changes in fuel prices will have effects on the quantities of other emissions-producing activities in the economy. By 2030, as compared to the base case, the STAX reduction scenario will lead to a reduction of total emission by 1.7 million tonnes while the DTAX reduction scenario will lead to a reduction of total emission by about 3.8 million tonnes (see Figs 6.3 and 6.4).

Figure 6.1: Reduction in fossil fuel emission (millions of tonnes of CO2) from tax on fuel and kerosene compared to the base case

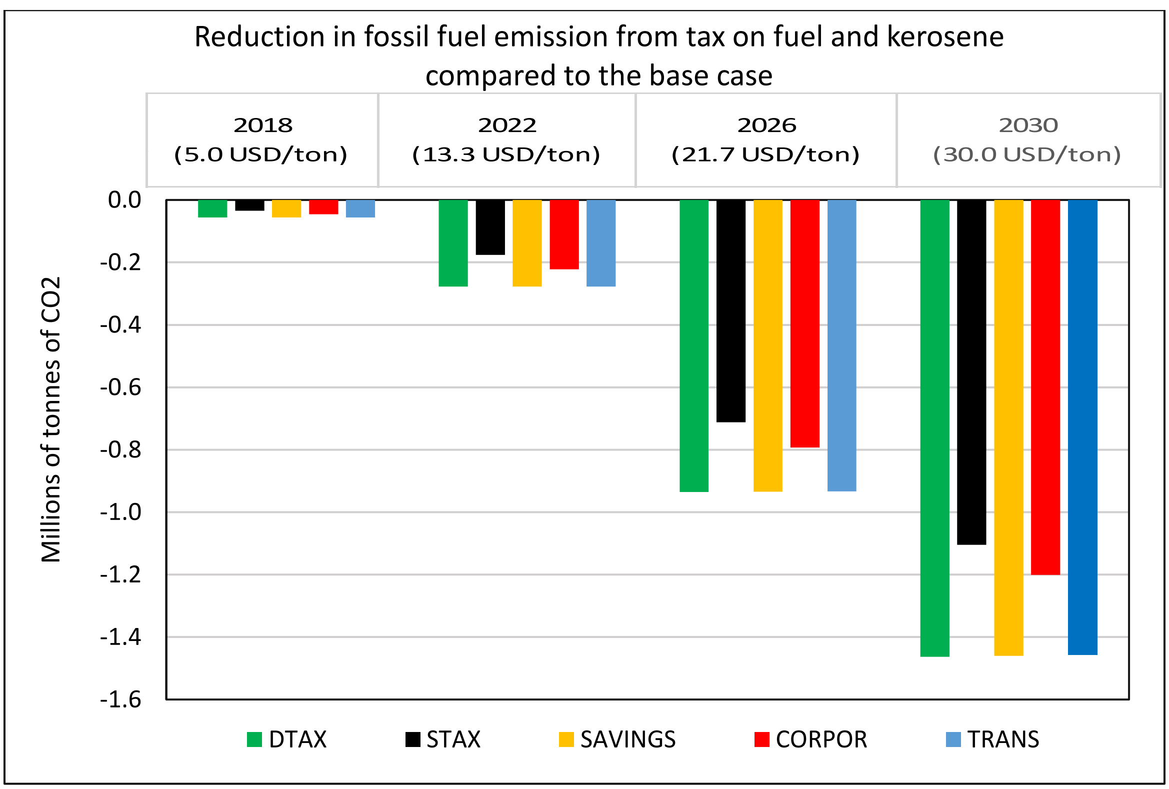


Figure 6.2: Percentage (%) change reduction in fossil fuel emission from tax on fuel and kerosene compared to base case

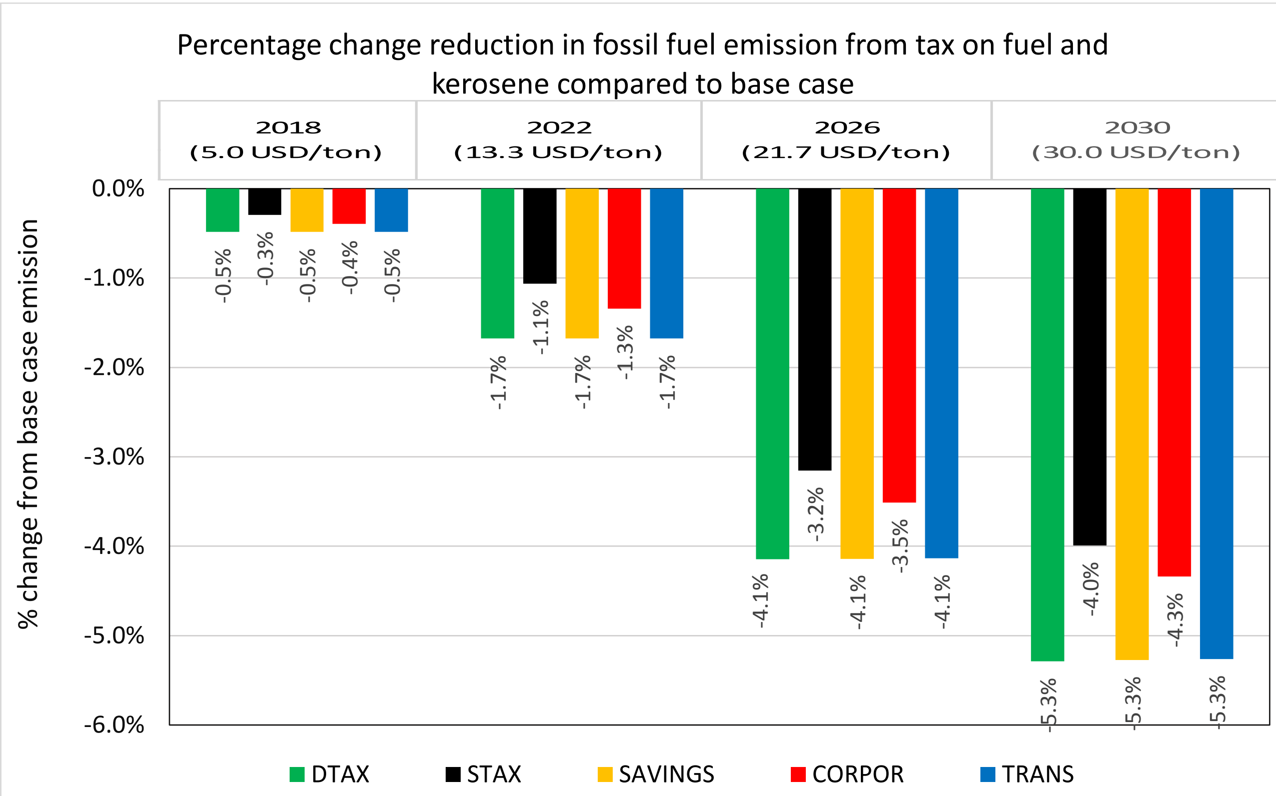


Figure 6.3: Total emission reduction in millions of tonnes from base case

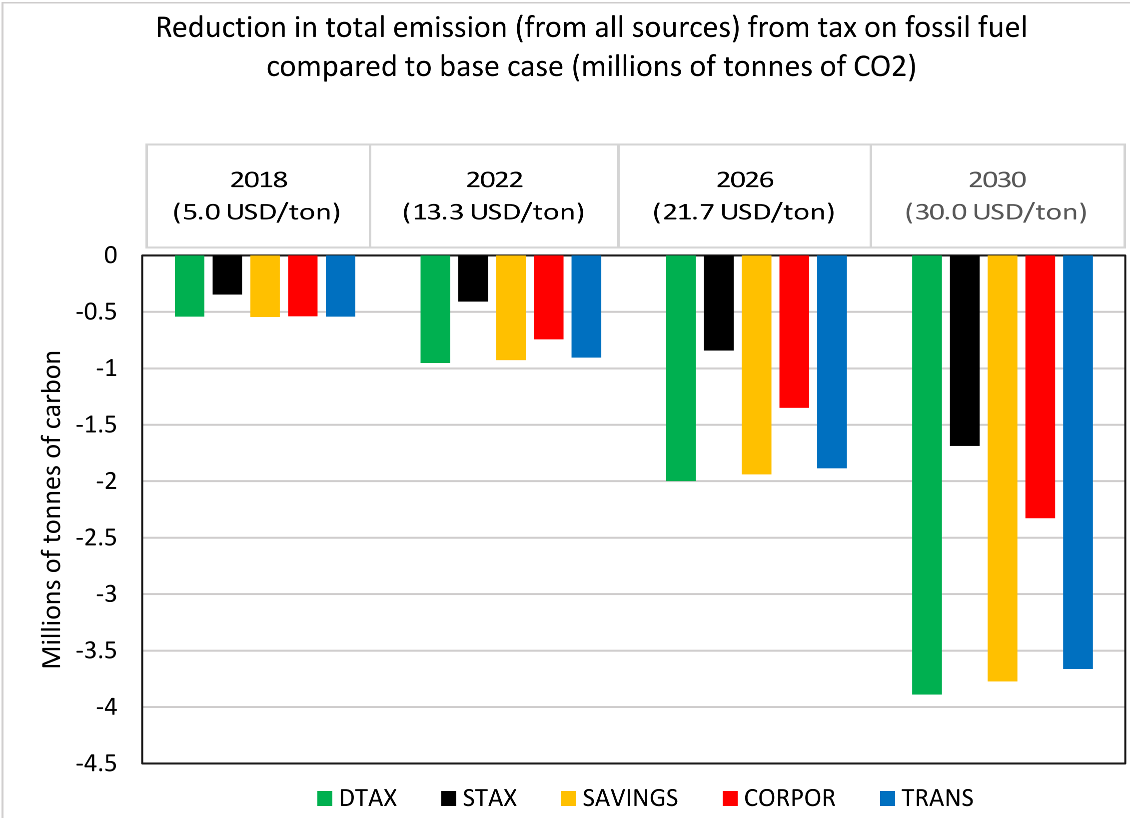
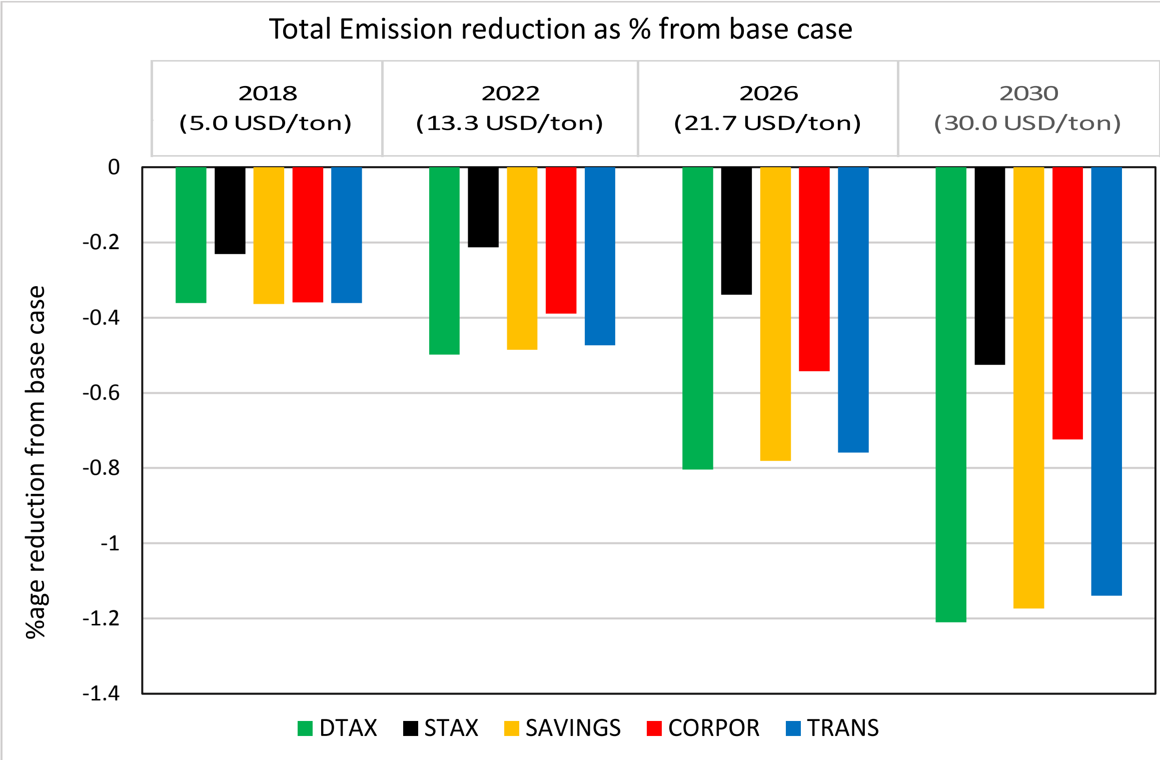


Figure 6.4: Total emission reduction as % from base case



6.2 Impacts on the Economy

The assumed time path of carbon prices has a fairly modest effect on the growth of GDP. In BAU, GDP is much higher in 2030 than in 2015 given the assumed growth rates for the economy. The same is true in the policy scenarios; the different tax and recycling combinations only slow growth by a little over the study period. GDP in 2030 is about 1 percent lower compared to BAU in almost all scenarios. Average GDP growth is from 0.38 to 0.52 percentage points lower with the carbon pricing than under BAU, depending on the chosen scenario. This is a small decrease in the growth rate of 7.6 percent per year in BAU.

Figure 6.5: Changes from base case average GDP growth rate (2018-2030)

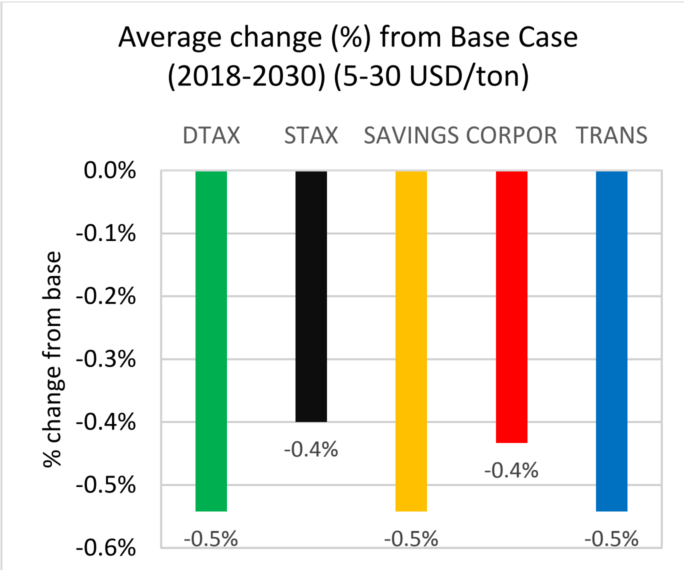
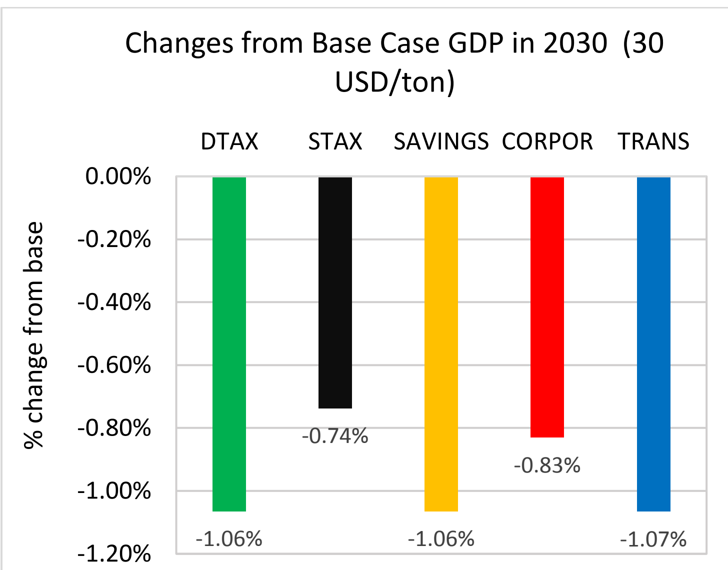


Figure 6.6: Changes from base case GDP in 2030



A cut in either sales or corporate tax leads to smaller negative effects on GDP compared to the other policy scenarios. The reason is that lower sales tax reduces cost of goods and services and stimulates demand across income groups. Lower business tax reduces the cost of capital which encourages investment and therefore employment and production. Both tax reductions end up reducing existing distortions in the economy. That, in turn, will lessen the amount of emission reduction from the carbon tax.

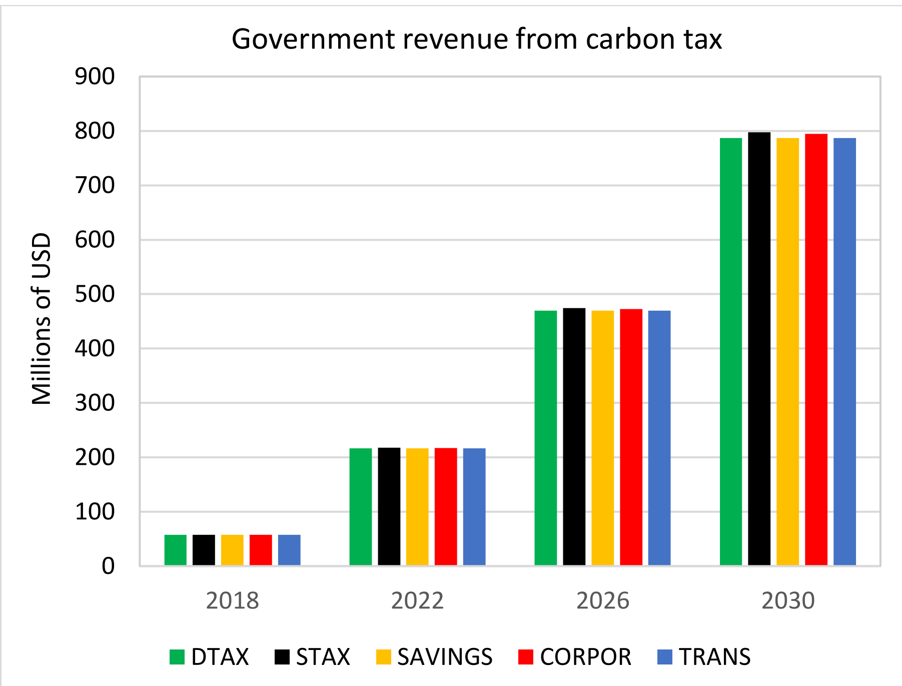
The scenario in which personal income tax is reduced leads to a larger decrease in the growth of economic activity. The reason is that professional and educated labor—the types of workers paying the personal income tax—is assumed to be fully employed. Reducing income tax therefore increases neither labor supply nor economic activity.

6.3 Fiscal Impacts

Because the government account should balance, and government expenditures are treated as fixed in the analysis, the government recycles the entire change in revenues in each of the five policy scenarios. To assess the amount of revenue raised through carbon pricing in each scenario, we first calculate the amount of fuel imported each year. We then multiply the fuel import by the emission factor (i.e., emission per unit of fuel) to arrive at a figure for total emissions, and then use the assumed carbon tax rate to calculate total carbon tax revenue.

The revenue generated in 2030 ranges from $786 million under the direct tax scenario to $798 million under the sales tax reduction scenario (Fig 6.7). The differences in revenue among scenarios are due to the differences in economic growth which, in turn, affect the demand for fuel.

Figure 6.7: Government revenue from carbon tax



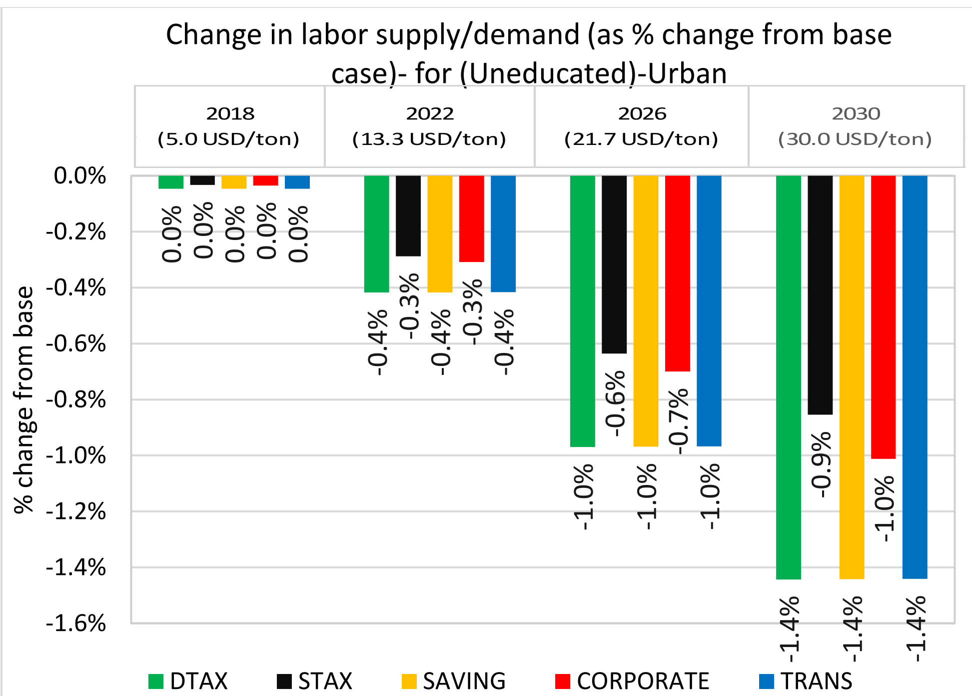
6.4 Distributional Impacts

Although the impact of the carbon tax on overall economic growth is one indication of the economic consequences of the policy, a much clearer understanding of the full implications for economic well-being comes from looking at the impacts across heterogeneous households based on factors such as their location (urban, rural) and their abilities (skilled, unskilled). Households receive income from wages (employment), returns on land for which they have the right of use, returns on capital they own, and income transfers. The implication of a carbon tax on a household's welfare, therefore, depends on how it affects each of these sources of household income.

In this subsection, we highlight the heterogeneous impacts on labor demand (employment) and household consumption. Figures 6.8 and 6.9 provide the difference in employment trend of low-skilled individuals located in the urban and rural sector. The carbon tax on fuels increases the price of goods reliant on fuel-using transport. As a result, it shifts demand away from those goods towards others. Sectors that are transport and thus fuel dependent include the service and manufacturing sectors. Both sectors are overwhelmingly concentrated in urban areas. As a result, there will be a decrease in urban unemployment (Fig. 6.8) among low-education workers. Because we assume full employment for high-skill individuals, they adjust to the carbon tax through a wage decrease rather than an employment decrease.

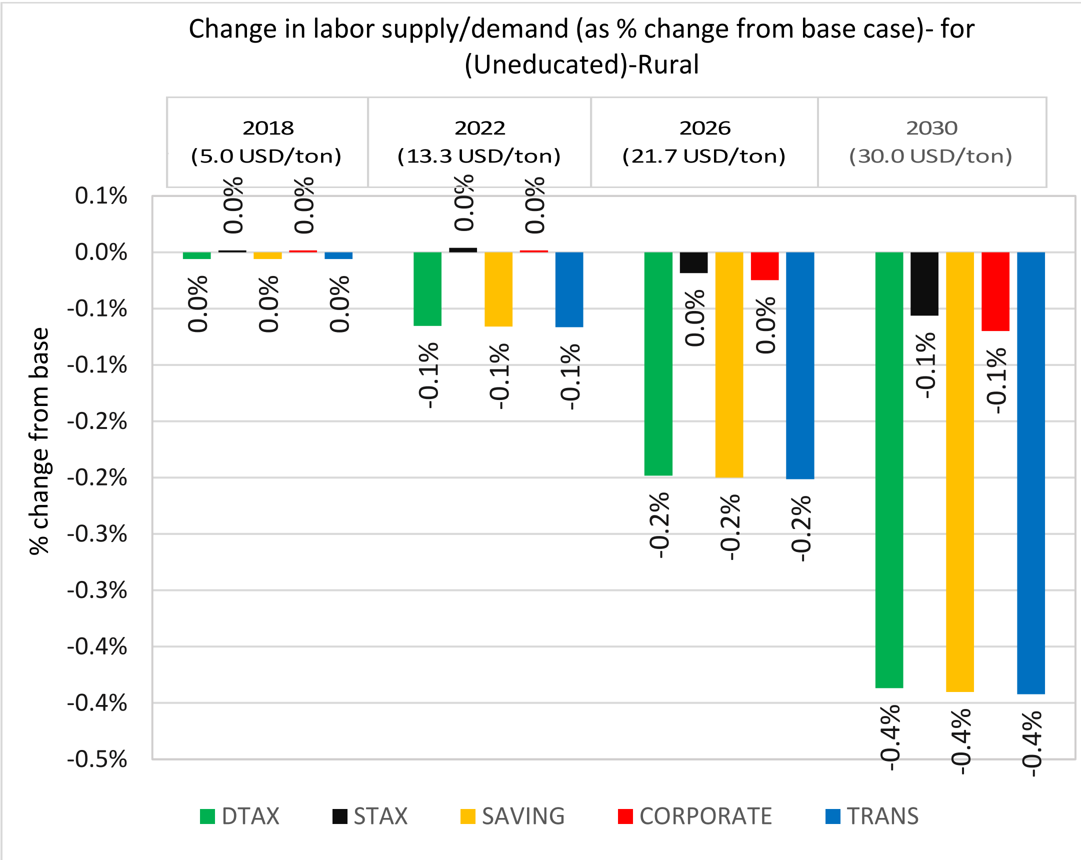
The agriculture sector, on the other hand, doesn't rely as heavily on transportation. Therefore, it benefits from an increase in demand relative to other goods. This, in turn, increases the employment potential of rural unskilled labor compared to their urban counterparts. Fig 6.9 indicates that there is almost no effect on employment across scenarios in rural areas compared to the base case scenario[7].

Figure 6.8: Changes in labor supply/demand for urban uneducated



[7] Note that in the base case scenario, employment of low-skilled individuals in urban areas is assumed to be 4,186,322 in 2018 and 6,290,527 in 2030. Similarly, employment of low-skilled individuals in rural areas is assumed to be 38,516,966 in 2018 and 54,301,218 in 2030.

Figure 6.9: Changes in labor supply/demand for rural uneducated

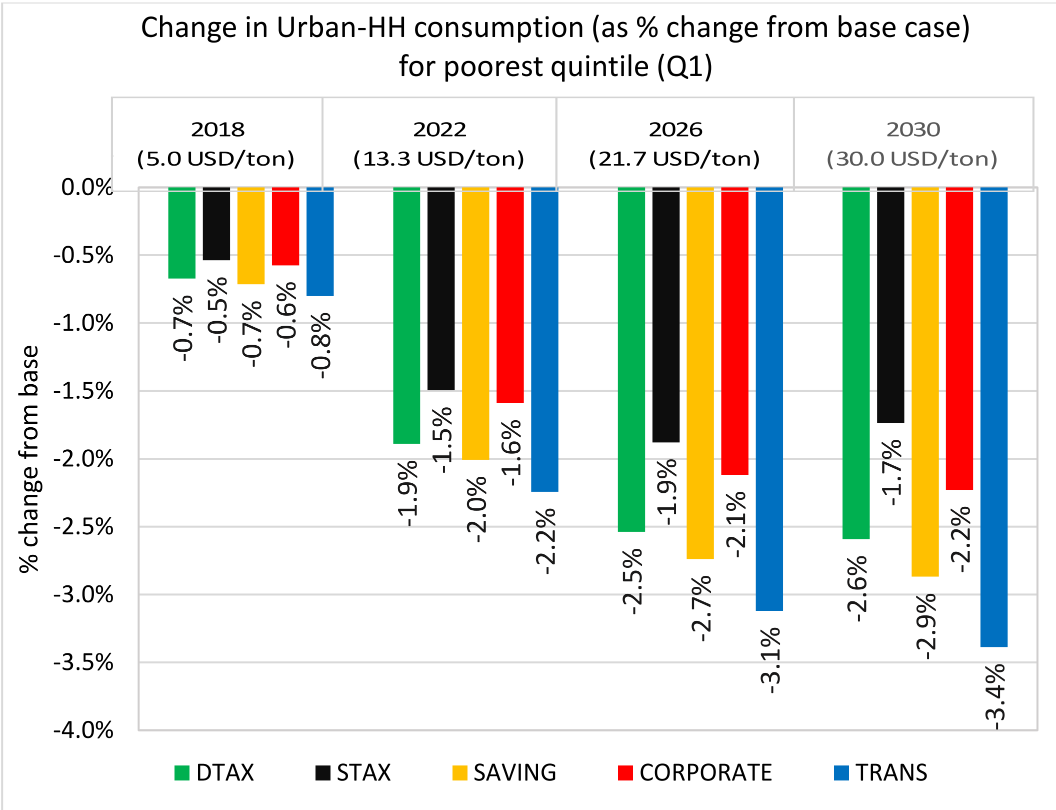


The tax has differing impacts on the consumption of lowest quintile households in urban and rural areas. In urban areas (Fig. 6.10), the main source of income for poor households is employment income (wages). As the sectors that poor households work in (services and industry) are affected more by the carbon tax, their income decreases due to either increased unemployment or a decrease in wage. The implication for economic welfare depends on the scenario: revenue recycling under STAX and CORPOR leads to smaller decline in consumption than others because there is less impact on the economy. TRANS, on the other hand, limits the decline in consumption by transferring resources to poorer households.

In rural areas, the 'almost non-existent' effect of the carbon tax on agriculture means that employment is not really affected. In addition, the tax slightly increases the return to land owned by rural households. The combination of these two effects implies that the impact of the carbon tax on the consumption of poor rural households is minimal[8].

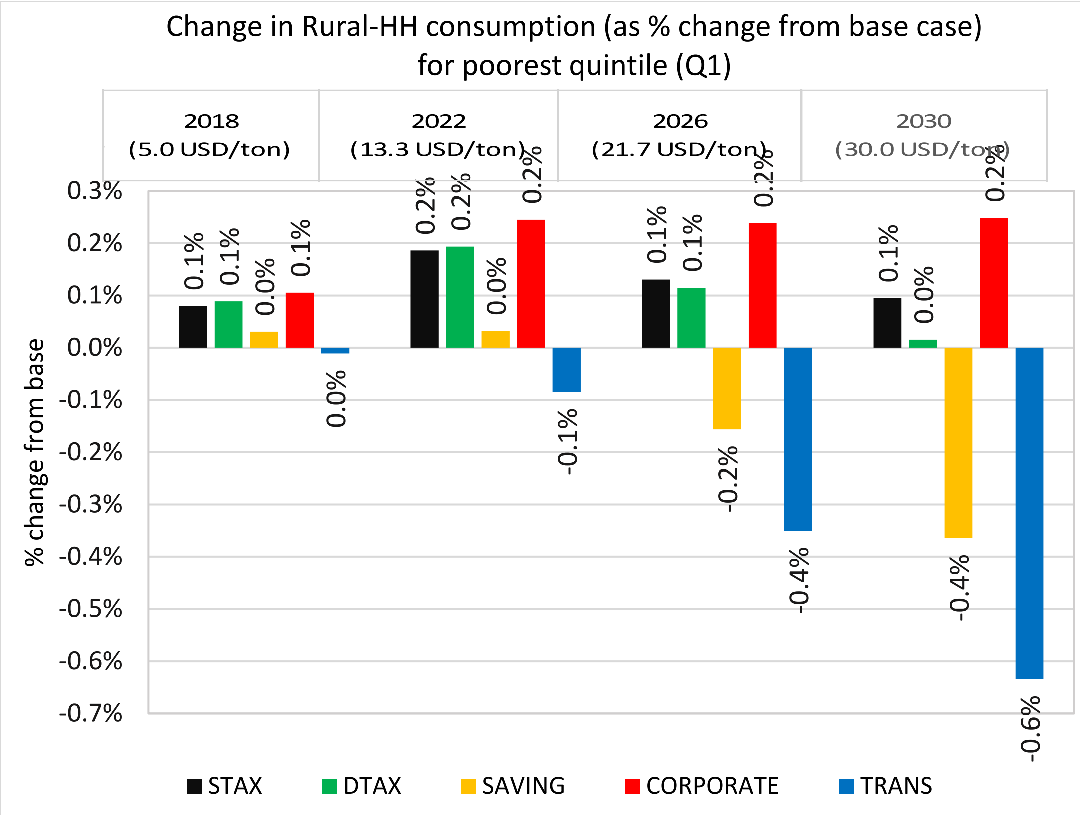
Figure 6.10: Urban household consumption (poorest quintile Q1)

8 Ex ante one would expect that the poor will fare better under the transfer scenario. However, the result shows the opposite. There are a couple of reasons for this. First, the transfer scenario doesn't restrict transfers to poor households. Since a large share of transfers are made to urban /richer households, it limits the extent to which the aggregate transfer can reduce poverty and inequality. Second, the slowdown in economic activity under the transfer scenario introduces unemployment/ wage reduction that affects welfare directly. Another way to understand the result under the transfer scenario is that one needs to restrict the transfer to poor households in order to achieve a meaningful reduction in poverty and inequality.



Change in Urban-HH consumption (as % change from base case)
for poorest quintile (Q1)
2018
(5.0 USD/ton)
2022
(13.3 USD/ton)
2026
(21.7 USD/ton)
2030
(30.0 USD/ton)
% change from base
0.0%
-0.5%
-1.0%
-1.5%
-2.0%
-2.5%
-3.0%
-3.5%
-4.0%
-0.7%
-0.5%
-0.7%
-0.6%
-0.8%
-1.9%
-1.5%
-2.0%
-1.6%
-2.2%
-2.5%
-1.9%
-2.7%
-2.1%
-3.1%
-2.6%
-1.7%
-2.9%
-2.2%
-3.4%
DTAX
STAX
SAVING
CORPORATE
TRANS

Figure 6.11: Rural household consumption (poorest quintile Q1)



7 Discussion

Over 90 percent of Ethiopia's GHG emissions comes from sources other than fossil fuels. This is because (a) energy use in general is relatively low, including in transport, although it is expected to grow as the economy expands; (b) most of Ethiopia's electricity comes from hydro; and (c) biomass remains the overwhelming choice of energy source for cooking. Consequently, application of carbon pricing to fossil fuels use in Ethiopia necessarily will have a somewhat limited effect on total GHG emissions.

Nevertheless, since motorization increases as incomes rise, the carbon price on fuels can contribute to mitigating a "lock-in" of high levels of individual vehicle use and high demand for road expansion by limiting vehicle use and creating support for expanding well-performing public transit and smaller, efficient cars in more densely populated areas. The carbon price on fossil fuels limits fuel use and associated GHG emissions cost effectively compared to what might result from a patchwork of different regulatory standards on various emissions sources. It creates incentives for increasing energy-efficiency including in transport choices. By moving away from carbon, Ethiopia may benefit in the long run from energy efficiency and relatively cheaper sources of energy, providing a competitive advantage over those countries that did not make the transition and have locked-in inefficient technologies.

Regarding economic impacts, GDP continues to grow substantially, albeit at a modestly lower rate. The direct effect of the carbon price is likely to be felt more by higher-income households since they are more intensive consumers of fossil fuels. Indirect effects through adjustments in the economy to higher fuel prices can lead to modestly slower growth for the urban poor, but the size of that effect will depend on how carbon revenues are recycled. Because the rural poor are not intensive users of fossil fuels, and the economic adjustments to carbon pricing may have limited impact on the agriculture sector, the rural poor are likely to face little impact from it.

A significant impact for Ethiopia of applying a carbon price to fossil fuels is that substantial revenues can be generated–up to $800 million per year by 2030. This revenue can be used in part for income transfers to soften impacts on the poor and to make revenue-neutral reductions in other taxes to spur investment and productivity gains. Another option for use of part of the revenue is to support other carbon mitigation activities, with a focus on those activities that have high societal co-benefits that strengthen the rationale for such public expenditures. Three such types of expenditures seem to stand out:

- Increase reforestation activities over and beyond what might be financed internationally through the country's REDD program. Investments in forest recovery can provide important ecosystem benefits, including soil and watershed protection and habitat for valued species, as well as expended carbon storage. This use of revenues is well aligned with the pillars of the CRGE (FDRE, 2011).
- Provide technology-neutral subsidies to increase affordability of improved cookstoves that use biomass fuel more efficiently or not at all, thereby reducing time spent collecting fuelwood and the substantial adverse health impacts of indoor smoke, especially for women and girls. Even if affordable alternatives to fuelwood for cooking take time to scale up in rural areas, cookstoves with improved fuel efficiency and improved ventilation can generate some improvement of indoor air quality, while reducing the level of unsustainable fuelwood harvest and the production of black carbon. Increasing access to cleaner cooking also is a pillar of CRGE (FDRE, 2011).
- Find ways to increase the efficiency of fossil fuel use in urban transport, thereby slowing its growth and the corresponding increase in GHG emissions. This could be done through investment in more fuel-efficient and less polluting multiple-rider transit vehicles in urban areas, thereby mitigating another major public health challenge. It would also be beneficial to use a portion of carbon pricing revenues to increase oversight of fuel quality.

As noted, emissions from agriculture and land clearing are more challenging to address through direct carbon pricing and the task will likely entail a mix of incentive-based and regulatory measures. A high priority for further analytical work toward achieving CRGE goals is to identify effective and affordable sets of such measures. There is a need as well for additional work to extend the scope of the CGE analysis. The CGE model used in this study for evaluating different options for applying carbon pricing to fuels is very much representative of current practice for this kind of analysis. Nevertheless, there are some important limitations of the model for capturing fully the impacts of a carbon tax.

The model does not explicitly differentiate between employment and output from informal and formal sectors of the economy. Recent research using CGE models in China, India, and Iran suggests that a significant informal sector leads to lower adverse impacts of carbon pricing (Bento, Jacobsen, and Liu, 2018; Mirhosseini, Mahmoudi, and Valokolaie, 2017)

The model also does not include the possibility of lasting structural unemployment for part of the labor force. A shift of tax burden away from labor supply financed by carbon price can lead to a reduction of economically inefficient under-utilization of available workers (Anger, Böhringer, and Löschel, 2010; Bosquet, 2000; Markandya, 2012). Relaxing the limitations noted here with a more advanced CGE model would represent a valuable direction for follow-up work.

Appendices

A. Detailed Methodology

The setup of CGE is based on a few crucial assumptions. A constant elasticity of substitution (CES) function governs the choice between factors of production which allows producers to respond to changes in relative prices and be able to substitute between factors of production subject to constant returns to scale in the process of profit maximization. This profit maximization implies that factors receive their marginal productivity. Once determined, these factors are combined with fixed-share intermediates using a Leontief specification. The use of fixed-shares reflects the belief that the required combination of intermediates per unit of output, and the ratio of intermediates to value-added, is determined by technology rather than by the decision-making of producers (Thurlow, 2008).

Producers can substitute between domestically sold and exported commodities based on constant elasticity of transformation (CET) function, which distinguishes between exported and domestic goods, and by doing so, captures any time or quality differences between the two products (Lofgren et al., 2002). Furthermore, the model includes three macro-economic balances or closures for government account balance, external account balance, and savings-investment account. To bring about equilibrium in the various macro accounts, these closure rules represent important assumptions about the way institutions operate in the economy and can substantively influence the results of the model. Closure rules are chosen due to their appropriateness in the Ethiopian context. For the current account, it is assumed that the level of foreign savings is fixed and the exchange rate is flexible. This implies that during shortage of foreign savings, the real exchange rate adjusts by simultaneously reducing spending on imports and increasing earnings from export to maintain a fixed level of foreign borrowing. In the government account, the tax rates are held constant and government savings are flexible implying the government finances its deficit through borrowing and is constrained in raising taxes to cover additional public spending. Savings-driven investment closure is adopted in which investment adjusts endogenously to the availability of loanable funds, and the savings rates of domestic institutions are fixed to ensure that savings equals investment spending in equilibrium. The consumer price index is chosen as the numéraire such that all prices in the model are relative to the weighted unit price of households' initial consumption bundle. The model is also homogenous of degree zero in prices, implying that a doubling of all prices does not alter the real allocation of resources (Diao et al, 2011).

This CGE model is calibrated to the 2010/11 Social Accounting Matrix (SAM) data of the country (Ahmed et al, 2017). The SAM is a comprehensive, economy-wide data framework, typically representing the economy of the nation and consistent with macro to micro accounting framework. Its construction is based on Ethiopia's national accounts, the Household Income Consumption and Expenditure Survey (HICES), Agricultural Sample Survey (AgSS), and other important data. Given that the SAM is a table which summarizes the economic activities of all agents in the economy, it typically includes households, enterprises, government, and the rest of the world (RoW). The relationships included in the SAM include purchase of inputs (goods and services, imports, labour, land, capital etc.), production of commodities, and payment of wages, interest rent and taxes, savings and investment, and the rest of the world.

This 2015/16 EDRI/IFPRI SAM is disaggregated in 69 activities: 31 in agriculture sector, 26 in industry, 11 in service, and 1 mining sector; 74-commodities; 13-factors[9], and 15[10]-households. The SAM also has

[9] Eight types of labor: four types in each location (urban and rural) by education type (no education, primary education, secondary education, and tertiary education), five types of capital (land, crop, livestock, mining, and other capital)
[10] Five farming households, five non-farming rural households, and five urban households.

government, different taxes, saving-investment, inventory and rest of the world accounts to show the interaction of different institutions within the economic system.

As briefly described above, this general equilibrium modeling involves the interactions of different actors in the economy including the activities that are linked to government income through value added and sales taxes; the households that supply and determine the level of factors of production and have implications on their income and subsequent level of direct income tax; and the level of imports which not only have implications on import duty but also on level of import tax , import VAT, and sales tax on domestically sold imported commodities; and the level of government transfer from the rest of the world.

B. Time Trend in the Structural Composition of the Ethiopian Economy

Table A.1. Sectoral composition of GDP in Ethiopia

	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
Sector	**1999/00**	**2000/01**	**2001/02**	**2002/03**	**2003/04**	**2004/05**	**2005/06**	**2006/07**	**2007/08**	**2008/09**
Agri-culture	55.3	56.4	54.5	49.8	52.1	52.6	52.3	51.2	49.5	47.8
Industry	9.7	9.5	10.2	11.0	11.0	10.7	10.6	10.4	10.3	10.2
Services	37.0	36.3	36.9	39.9	38.0	38.0	38.6	39.8	41.6	43.1
Total	100.5	100.5	100.2	100.3	100.3	100.3	100.5	100.5	100.7	100.7
Less: FISIM	0.6	0.6	0.4	0.4	0.5	0.5	0.6	0.6	0.7	0.7
GVA at Constant Basic Prices	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Sector	2002 2009/10	2003 2010/11	2004 2011/12	2005 2012/13	2006 2013/14	2007 2014/15	2008 2015/16
Agriculture	**46.5**	44.7	43.1	42.0	40.2	38.7	36.7
Industry	**10.3**	10.5	11.5	13.0	13.8	15.0	16.7
Service	**44.1**	45.5	45.9	45.5	46.6	47.0	47.3
Less: FISIM	0.7	0.7	0.6	0.5	0.6	0.6	0.7
GVA at Constant Basic Prices	100	100	100	100	100	100	100

Source: NPC (2016)

C. Carbon Content Analysis (Input Output Multiplier Approach)

A version of input-output multiplier analysis, a variant of Leontief (1970), that recognizes the fact that activities produce multiple products and products are produced by multiple activities is introduced in Arndt, *et al*. (2013). We follow this approach to estimate the carbon content of activities and products in the Ethiopian economy.

Suppose we define $a\ (N+K)\ x\ 1$ matrix (X) that consists of N activities and K commodities. Suppose we also have an (N+K x N+K) matrix A that consists of NxN zeros in its upper left quadrant, NxK coefficients in its upper right quadrant that signify the proportion of domestic supply of the commodity by the activity, KxN matrix of coefficients in its lower left quadrant that describe the proportion of the commodity that is used to produce final output of an activity. Suppose we also define the final demand of the product of an activity and commodity by an (N+Kx1) matrix F where the first N elements represent the amount of the activity that is self-consumed. The rest, i.e. K, represents the amount of the commodity that is consumed by households, government, saved, or exported to the rest of the world.

We can readily express the relationship outlined above in the following simple linear equation form.

$$X = AX + F$$

Simple linear algebra reveals that gross output of an activity can be expressed as follows:

$$X = \ (I - A)^{-1}F$$

Each column of the matrix $(I\text{-}A)^{-1}$ describes the amount of gross output or supply (i.e., output for the N activities and supply for the K commodities) that must be produced/supplied to have the final demand amount of the first element of the final demand matrix.

Let C be a $(N+K, Z)$ matrix that contains information about the total carbon emitted in the economy due to carbon source **z** (fuels, kerosene, fertilizer, firewood, livestock). Each column contains a non-zero value for sources of emission and zero for other activities and commodities.

Let X be a $(N+K, 1)$ matrix that reflects the total quantity of the carbon source supplied in the economy (i.e. activities and commodities). Then $Y = X * I$ is a diagonal matrix $(N+K, N+K)$ that contains element xi in the diagonal.

Then $M = Y^{-1}C$, an $N+K\ x\ Z$ matrix, is the carbon content of a given amount of gross product of the activities and commodities in the economy.

We can convert the above equation into carbon emission by final demand as follows: $M'(I\text{-}A)^{-1}$. This expression, a $\mathrm{Z\ x\ N + K}$ matrix, provides us with information on how much emission there is per unit of final demand of each good. Multiplying this expression with the value of the final demand results in the carbon emission (direct and indirect) by each commodity.

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