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South Africa Carbon Pricing and Climate Mitigation Policy

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South Africa Carbon Pricing and Climate Mitigation Policy
Prepared by Haonan Qu, Suphachol Suphachalasai, Sneha Thube, and Sébastien Walker*

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ABSTRACT: Meeting South Africa's ambitious climate objectives will require a comprehensive strategy that includes a more effective use of carbon pricing policy, reducing inefficient government subsidies that have delayed the green transition, well-targeted support to affected industries and households, and other green financial and sectoral measures. Implemented well, the mitigation policy package would promote low-carbon investments, raise government revenues, and support economic growth.

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SELECTED ISSUES PAPERS

South Africa Carbon Pricing and Climate Mitigation Policy

South Africa

Prepared by Haonan Qu, Suphachol Suphachalasai, Sneha Thube, and Sébastien Walker[1]

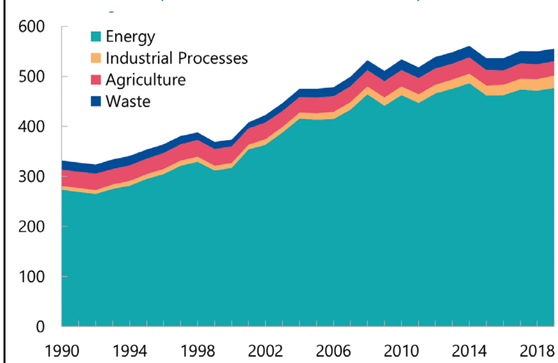
[1] The authors would like to thank the South Africa authorities for their helpful discussions and comments.

A. Existing Carbon Pricing in South Africa

1. **South Africa has ambitious climate mitigation goals.** South Africa is the largest greenhouse gas (GHG) emitter on the African continent. Its total GHG emissions (excluding forestry and other land use) increased by over 67 percent from 1990 to 2019 (Figure 1). The energy sector accounted for close to 86 percent of the emissions in 2019 and contributed to almost 91 percent of the GHG emission increase over the past three decades. The emission profile reflects the carbon-intensive electricity generation in the country which mostly relies on coal-fired power plants. Transition towards a green and climate resilient economy is already part of the country's National Development Plan 2030.[1] In its updated Nationally Determined Contribution (NDC), South Africa committed to reduce its GHG emission to 350–420 MtCO2e by 2030 and reach carbon neutrality by the midcentury. Thus, meeting these objectives will require climate mitigation policies.

Figure 1. Historical GHG Emissions

(In million tons of CO_2e)



Sources: WRI (2022).

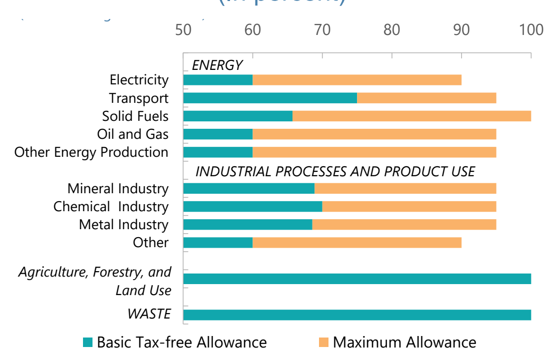
Note: GHG emissions exclude land-use change and forestry (LUCF) and bunker fuels emissions.

2. **Consistent with the climate ambition, South Africa is the first African country to adopt a carbon tax policy.** The carbon tax was implemented in June 2019 as an important policy lever for the country's mitigation strategy. The tax follows the polluter-pays-principle and is imposed on fuel inputs based on emission factors and procedures in line with the standards published by the Intergovernmental Panel on Climate Change. The tax covers about 90 percent of the country's total GHG emissions, with only agriculture, forestry, land use, and waste excluded.

3. **A phased approach of the carbon tax regime was introduced to ease the transition.** Reflecting concerns related to competitiveness and impact on low-income households of the carbon tax, transitional tax-free thresholds, allowances, and carbon offsets were introduced during the transition phase of the carbon tax. As a result, there is a basic tax-free allowance ranging between 60 percent and 75 percent of emissions across sectors, with additional allowances and offsets potentially adding up to 95 percent depending on the sector, except for those that have been completely excluded (Figure 2). Mimicking features of a sectoral feebate programs, the carbon tax regime allows performance adjustments through which the tax-free threshold is adjusted using a carbon emission intensity factor for output relative to a sector benchmark, although the adjustment is capped at 5 percentage points. There are also additional tax-free

Figure 2. Emission Tax-Free Thresholds for Selected Industries

(In percent)



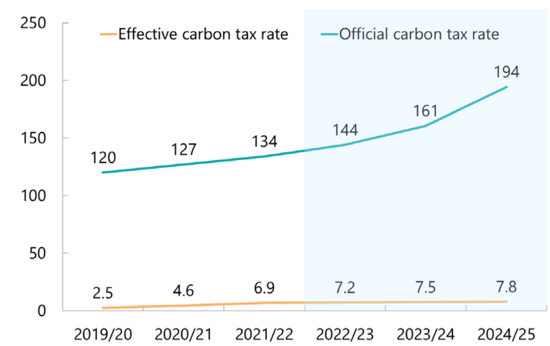
Sources: South Africa Carbon Tax Act 2019 and IMF staff calculations.

[1] South Africa Government (2012).

allowances possible for participants in the country's carbon budget system, companies with significant trade exposure, and those utilizing carbon offsets.

4. **The generous tax-free thresholds and allowances contributed to a low effective carbon tax rate in South Africa.** The official carbon tax rate was set at R120 (or about $7) per ton of CO2e initially and increased to R134 (or about $8) by end 2022. However, based on the carbon tax revenue collected, the estimated effective rate was less than R7 per ton of CO2e during the FY2021–22 (Figure 3). With the transition phase of the carbon tax extended from end 2022 to end 2025, the effective carbon tax rate is expected to remain low, despite of the planned increase in the headline official rate in the coming years.

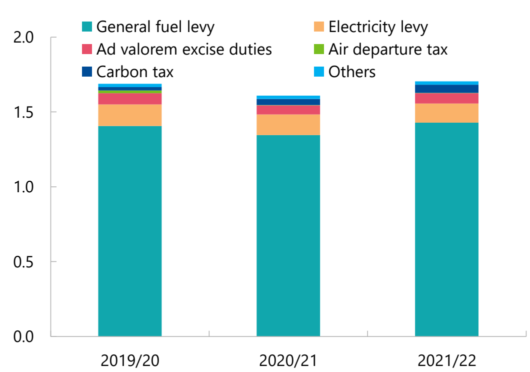
Figure 3. Carbon Tax Rate
(In rand per Ton CO2e)



Sources: National Treasury (2022) and IMF staff calculations.

5. **In addition to the carbon tax, there are other policy instruments that influence carbon pricing in South Africa.** There are a number of environment-related taxes at both the national and the local government level, which include transport fuels, vehicle taxation, aviation taxes, product taxes, electricity, water supply, and wastewater. Revenue from the national level tax instruments accounted for about 1.7 percent of GDP on average in recent years (Figure 4). The general fuel levy was the major instrument, accounting for close to 84 percent of the total. It significantly raised the price of carbon in South Africa compared with other G20 countries (Figure 5).

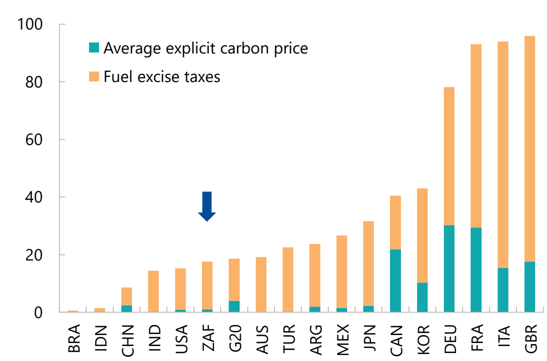
Figure 4. Environment-Related Taxes
(In percent of GDP)



Sources: National Treasury (2022), and IMF Staff calculations.

Note: Others include plastic bag levy Universal Service Fund, levies on financial services, CO 2 motor vehicle emissions, incandescent light bulb levy, turnover tax for micro businesses, tire levy, International Oil Pollution Compensation Fund.

Figure 5. Carbon Price, 2021
(EUR per ton of CO2e)



Source: OECD (2021).

Note: G20 includes all G20 countries, except Saudi Arabia. Explicit carbon price refers to price that uses carbon taxes and emissions trading systems to raise the cost of carbon-intensive fuels.

6. **Prior to the carbon tax, an electricity generation levy was introduced to help with the country's long-term climate objectives.**[2] It is worth noting that most of the existing environment-related tax instruments prior to the carbon tax were introduced with the intention of raising revenue, rather than focusing on the

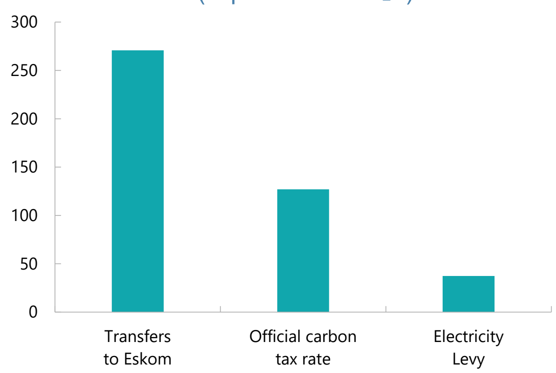
[2] National Treasury (2015).

environmental considerations in their designs. One exception is the electricity levy introduced in 2009 on the power generation from fossil-fuel and nuclear sources. The purpose was to mitigate electricity shortages as a demand-side management tool and to expand the country's energy-efficiency tax incentive programs. During the transition phase of the carbon tax, the energy sector can use the electricity generation levy to offset its carbon tax labilities.

7. **Large government transfers to the carbon-intensive energy sector significantly reduce the effective price of carbon in South Africa.** Eskom, the state utility monopoly, relies primarily on coal to fuel its power plants and depends on large transfers from the government to continue operating. Eskom currently enjoys the offset from the electricity levy paid under the Carbon Tax Act and, with the extension of the transition phase, does not expect to have a liability for the tax until 2026. Eskom currently pays the electricity levy on power produced from non-renewable sources, but subsidies to Eskom on a rand per ton of CO2e basis are vastly greater than both the electricity levy on the same basis and the official carbon tax rate (Figure 6). This, together with the uncertainty over when Eskom will become liable for the carbon tax, provides little incentive for Eskom to move away from coal-fueled generation. Moreover, Eskom's challenges in reducing its costs and the need to ensure availability of power will likely result in continued subsidies to the sector (Figure 7).

Figure 6. Transfers, Carbon Tax, and Electricity Levy, FY2020/21

(R per ton of CO_2e)

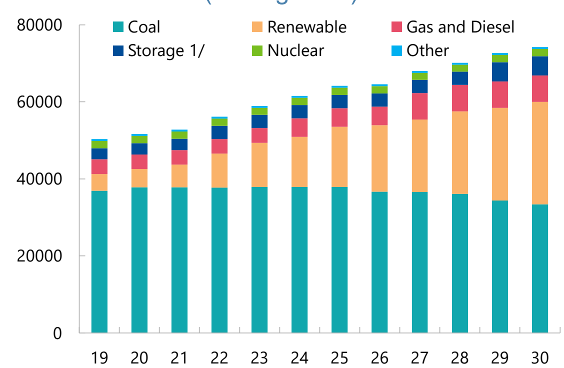


Sources: Eskom, IMF Staff calculations.

Note: "Transfers to Eskom" are government transfers to Eskom divided by the company's CO_2-equivalent emissions. Eskom is currently exempt from the carbon tax. Electricity levy is the environmental levy on electricity generated in South Africa from non-renewable sources and revenues from non-Eskom producers are assumed to be negligible.

Figure 7. Electricity Generation Capacity Projection

(In megawatt)



1/ Storage systems for electricity include battery, flywheel, compressed air, and hydrogen fuel cells, etc.

Source: IRP 2019.

B. Challenges in Meeting South Africa's NDC

8. **The government has laid out a long-term plan for the carbon tax rate path.** In the 2022 Budget and the 2022 Draft Taxation Law Amendment Bill, the government proposes to strengthen the carbon tax policy by progressively raising the carbon tax rates between 2023 and 2030, as well as providing a long-term carbon tax trajectory up to 2050 and beyond. After the transition phase of the carbon tax ends in 2025, the government plans to raise the carbon tax rate to at least US$20/tCO2 by 2026, to US$30/tCO2 by 2030, and accelerating to higher levels up to US$120/tCO2 beyond 2050.

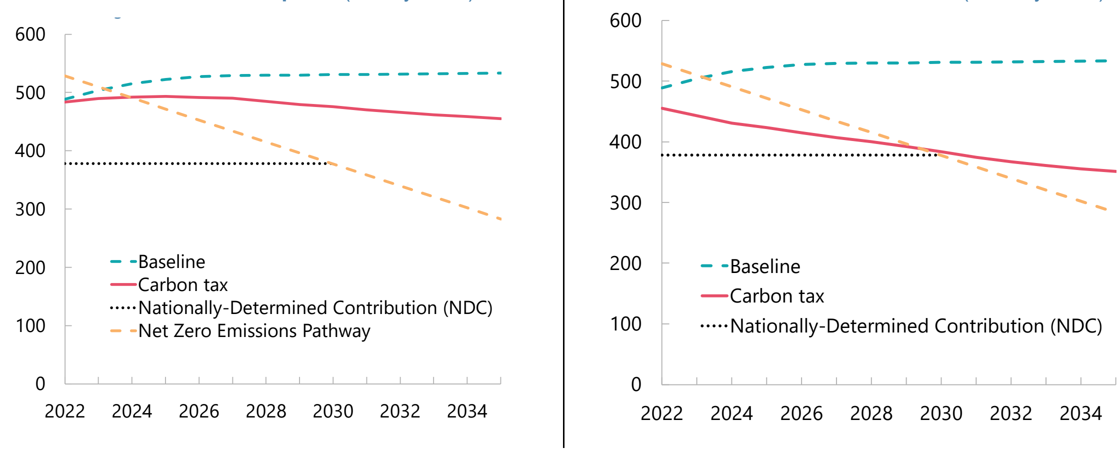
9. **The Carbon Pricing Assessment Tool (CPAT) is used to simulate the impacts of the proposed carbon tax rates scenario.** The CPAT is based on a reduced-form model of energy consumption that

incorporates growth forecasts, price and income elasticities, exogenous and endogenous rates of technical progress, and price changes.[3] By using input-output tables and household expenditure survey data, the model also offers insights into the distributional impact of carbon pricing across different industries and income groups of South African households.

10. The current projected path of South Africa carbon tax rate is, by itself, likely to fall short of South Africa's NDC. The results from the CPAT suggest that raising the carbon tax rate to envisaged levels alone will not be enough for South Africa to meet its emission targets. The NDC makes commitments to curb GHG emissions within the range of 350–420 MtCO2e during 2026–2030, or between 15 to 30 percent reduction from the current level. The CPAT model shows that the current carbon tax proposal, albeit making a significant contribution to emission reduction effort, would result in GHG emissions in the range of 475–492 MtCO2e during 2026–2030 (Figure 8A). It is important to note that, for simplicity, the simulation assumes that there is no tax exemptions or allowances over the modeling period and the carbon tax is the only policy instrument deployed.

Figure 8. GHG Emissions under Alternative Carbon Tax Scenarios
(In million ton of CO_2e)

A. The Current Tax Proposal ($30 by 2030) | **B. Carbon Tax Needed for NDC** ($120 by 2030)



Sources: IMF Staff calculations.

Note: Baseline emission coincide with South Africa's business-as-usual emissions (see, e.g., South Africa Government (2022) and Climate Action Tracker); Both scenarios assume no tax exemptions/allowances. The NDC emission level represents the mid-point of the range of commitments presented in the NDC.

11. Reaching the emission reduction targets as planned would require higher effective carbon tax rates. An alternative carbon tax scenario is constructed under the CPAT that would result in emission reductions that meet the NDC target. Figure 8B depicts a scenario where the carbon tax rate is raised to $120/tCO2 by 2030. This is projected to result in the levels of GHG emissions within the range of 377–453 MtCO2 during 2026–2030, consistent with the NDC commitment range. By 2030, the GHG emission is expected to reduce to the mid-point of the NDC target under this scenario. The results also suggest that, for South Africa to achieve the net zero target by the midcentury, the carbon tax rate needs to ramp up faster after 2030 and rise above $120/tCO2. Furthermore, this scenario implies that the current proposal in the 2022

[3] The CPAT was developed by IMF and World Bank staff and evolved from an earlier IMF tool used, for example, in IMF (2019a and b). For descriptions of the model and its parameterization, see IMF (2019b) Appendix III, and Parry and others (2021), and for further underlying rationale see Heine and Black (2019).

budget to raise the carbon tax to $120/tCO2 after 2050 would not deliver the NDC and the net zero target in the absence of additional mitigation measures.

C. Complementary Climate Mitigation Measures to Carbon Tax

12. **Many other countries face similar challenges in meeting their NDCs and often resort to multiple policy instruments.** Countries rely on different combinations of a wide range of price-based and non-price-based policies that suit country-specific circumstances to reduce GHG emissions. International experiences show that a comprehensive package of policies is needed to support ambitious climate mitigation goals. As for South Africa, the carbon tax is key but needs to be complemented by other policies and investment measures. As envisaged in the NDC, the carbon tax is among other instruments and measures including the Integrated Resources Plan (IRP), the Green Transportation Strategy, and the enhanced energy efficiency programs. The draft Climate Change Bill also articulates the carbon budgets and the sectoral emission targets. The Just Energy Transition Investment Partnership is an important flagship initiative that would help leveraging various public and private financing sources to support South Africa's long-term vision of a just transition.

13. **South Africa's policy package should help meet the climate objectives if policy instruments are aligned.** The combined effect of policies varies greatly across countries (Figure 9A). The carbon tax and planned investment in renewable energy as articulated in the IRP are expected to be the main drivers of South Africa's emission reduction effort. This, together with the carbon tax trajectory proposed in the 2022 Budget suggest a strong commitment to meeting climate objectives. But putting in place these policies and implementing them effectively will be critical. In carbon price equivalent terms, South Africa's policy package translates to approximately $30t/CO2 based on the current carbon tax and sectoral policies (Figure 9B). With a range of existing and new policies on the table, it is crucial to ensure that the various policy instruments are well aligned to support the NDC objectives and are not in conflict with each other.

14. **The carbon tax and the carbon budgets in South Africa's policy package need to be integrated.** In addition to the carbon tax, South Africa plans to use company-level carbon budgets as part of the policy package to achieve NDC goals. The carbon budgets will provide GHG emissions allowance, against which emissions from the operations of a company will be tracked. If a company or an entity has been allocated a carbon budget, it must prepare a GHG mitigation plan which outlines the measures that will ensure that the company stays within its allocated carbon budget.[4] There are strengths and weaknesses associated with carbon tax and carbon budget approaches.[5] It is therefore important to coordinate the two policies to ensure their consistency and desirable emission reduction outcomes.[6] To address concerns about potential double penalties from the two instruments, the government proposes to set a higher carbon tax rate of R640/tCO2 for GHG emissions exceeding the carbon budget in the transition phase of the carbon tax (and no penalty for non-compliance for the carbon budget). However, it is not clear how the penalties will be adjusted or aligned with the new proposal of carbon tax rates from 2026 onward.

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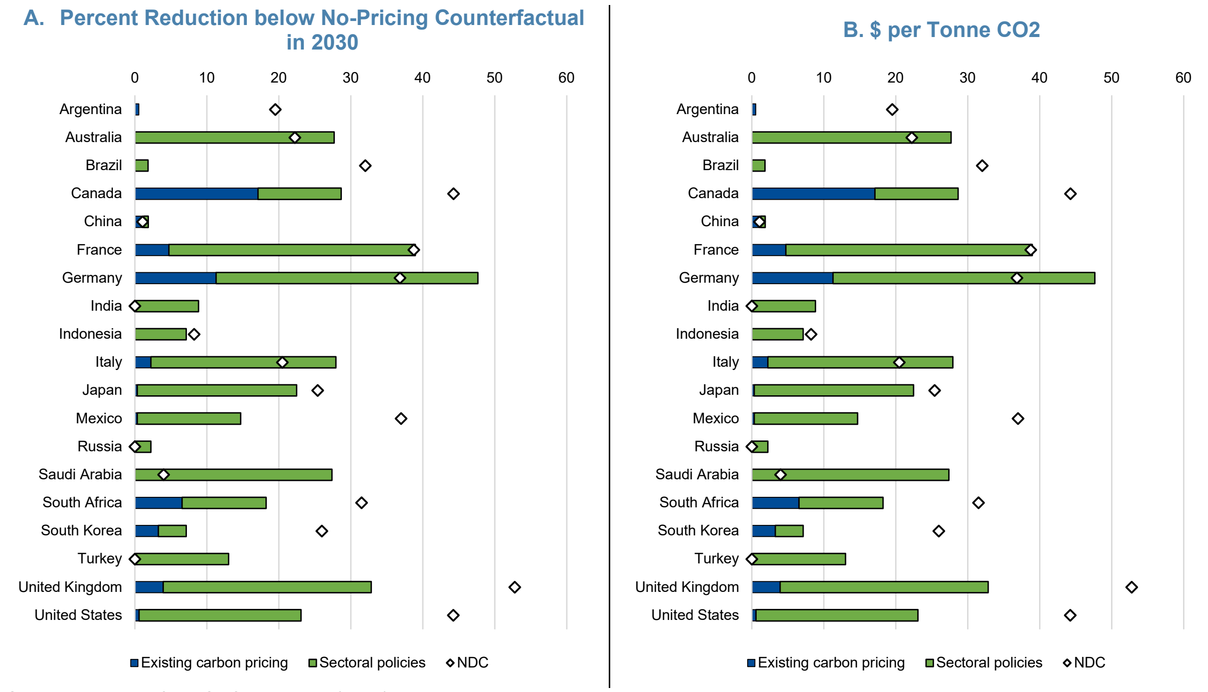
[4] The mandatory carbon budgeting system will come into effect once the Climate Change Bill is enacted, and the carbon budget allowance of 5 percent under the carbon tax will be phased out.

[5] For instance, there is greater uncertainty on emission outcomes from a carbon tax, compared to a carbon budget. However, a carbon tax is considered more cost-effective to administer and more equitable (the same tax rates apply to all sectors, whereas a carbon budget is determined at the firm-level and vary across entities). For more detailed discussion, see Partnership for Market Readiness (2017).

[6] In particular, the incentives for emission reductions and disincentives for non-compliance across the carbon tax and the carbon budget should be well aligned.

Figure 9. Combined Effects of Current Policies and Sectoral Targets



Sources: Adapted from OECD and IMF (2022).

15. Sectoral feebates could help promote mitigation across sectors and reinforce a carbon tax. Feebates apply a revenue-neutral, sliding scale of fees on activities with above-average emission rates and a sliding scale of rebates on activities with below-average emission rates. Feebate schemes do not impose a fiscal cost to the government and can help with acceptability because (unlike carbon pricing) they avoid the burden of higher energy prices on the average household and firm. In South Africa, the existing performance benchmark allowances under the carbon tax, and the carbon budgets that penalize emissions above the allocated budgets (through higher tax rate) have similar features to feebates.

16. Green financial policy could play an important role in mobilizing the much-needed private sector climate finance. Financing needs for the decarbonization transition could amount to 4 ½ percent of GDP per year between 2022 and 2050, requiring private finance.[7] Green financial sector reforms can help crowd-in private sector climate finance and enhance financial sector resilience. To this end, the government can play a major role in creating an enabling environment, de-risking green investments, and removing critical regulatory and business barriers. This, in turn, helps lowering the necessary levels of carbon tax to meet climate mitigation targets. National Treasury (2021) provided concrete actions including, for instance, providing guidelines for reporting and disclosure of climate-related risks, providing guidelines for climate stress testing, and scaling-up green bond issuance building on the green finance taxonomy.[8]

17. Addressing the carbon intensity of energy generation in South Africa should be a priority. This will require phasing out exemptions from the carbon tax, raising the carbon tax rates as planned, removing

[7] World Bank Group (2022).

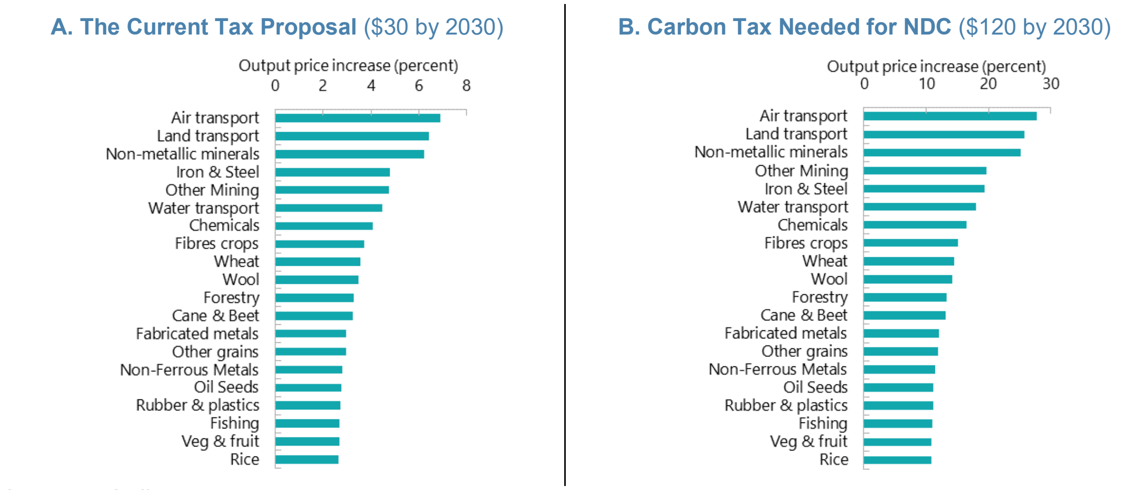
[8] In 2022, South Africa's first national Green Finance Taxonomy was launched by the Taxonomy Working Group chaired by National Treasury. Their latest work on the issue can be found via https://sustainablefinanceinitiative.org.za/working-groups/taxonomy-working-group/.

regulatory barriers for alternative green energy generation, promoting contestability in the energy sector, as well as providing enabling conditions to crowd in green private sector investments.

D. Distributional Consequences from Carbon Pricing

18. The impact of higher carbon pricing varies significantly across sectors. The carbon tax policy will have differentiated impacts across economic sectors. The NDC-aligned carbon tax scenario would add tremendous pressure on output prices compared to the current carbon tax proposal (Figure 10A and 10B). Carbon price in the CPAT model simulation is assumed to pass through to energy prices, with the largest effect on coal prices followed by natural gas, oil, as well as electricity prices. Increases of fuel and electricity prices in turn push up output prices. The transport and industry sectors are the most vulnerable in both carbon tax scenarios.[9]

Figure 10. Price Impacts Under Alternative Carbon Tax Scenarios



Source: IMF Staff calculations.

19. Differentiated effects across sectors indicate profound shifts in the economy. Sectoral changes in value-added and employment are estimated using the global dynamic CGE model IMF-ENV, which captures economic interlinkages across sectors and countries.[10] Two scenarios are modelled based on the upper and lower bound of South Africa's 2030 GHG emission target range of 350–420 MtCO2e. While the model simulations suggest a relatively mild overall growth impact,[11] the differentiated effects across sectors could be substantial. In the NDC target range, the energy-intensive and high-carbon sectors contract while there is expansion of green and low-carbon sectors (Figure 11A). The value-added in the fossil extraction sector can fall between 17 to 31 percent relative to the baseline scenario. A smaller decrease in value-added is also seen in iron and steel, chemicals and non-metallic mineral sectors which are typically energy intensive. Substantial

[9] As part of the extension of the transition phase of the carbon tax policy, the government continued to allow taxpayers to deduct payments of the electricity generation levy and additional purchases of renewable electricity from their carbon tax liability until end 2025. This measure is estimated to help alleviate electricity price increase by 17 percent since the carbon tax policy came into effect. However, similar to the rest of the paper, the CPAT simulation results do not include any tax-free allowance and exemptions.

[10] IMF-ENV represents 36 sectoral and 26 regional aggregates and, this granularity in capturing economic interlinkages between sectors and across countries makes its strong tool to assess the impacts of structural changes (see Appendix A for a non-technical description of the model).

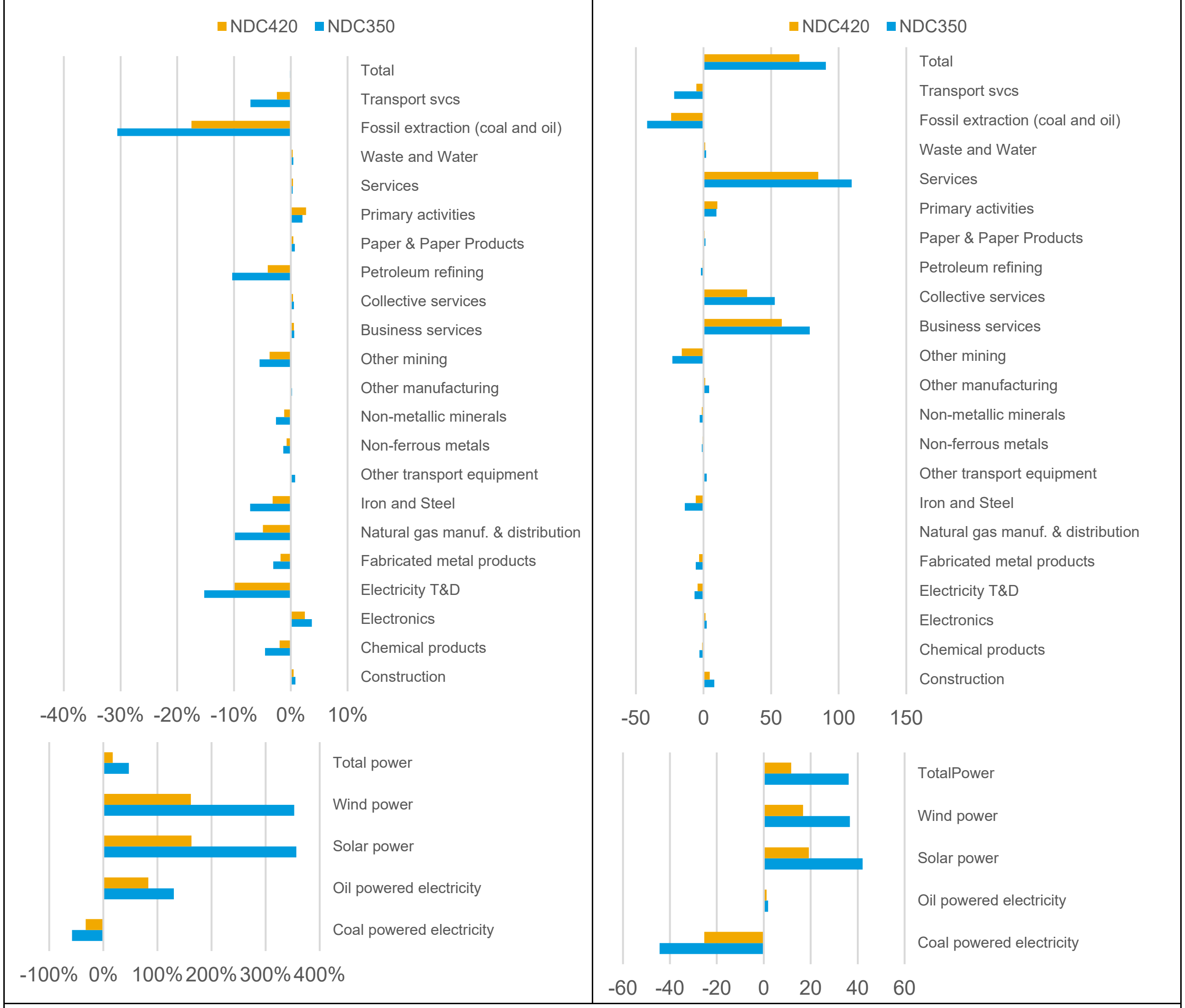
[11] Under NDC350 and NDC420 pathways the annual GDP growth rate between 2022–2030 reduces by 0.04 to 0.12 percentage points relative to the baseline growth rate.

shift in value added to less carbon-intensive sectors is observed in the power sector, highlighting the importance of the sector for the success of South Africa's climate mitigation strategy. Overall, the value added in the power sector can increase by 17–47 percent relative to the baseline, with the overall share of renewables in 2030 increasing from 10 percent in baseline to 30–53 percent. Though coal remains the biggest source for electricity generation in 2030, its share is falling over the years with growing demand being increasingly supported by renewables.

Figure 11. Sectoral Impacts under NDC Scenarios

A. Changes in Sectoral Composition of Real Valued Added (at factor cost) in 2030 (% change rel. to Baseline)

B. Changes in Sectoral Composition of Employment in 2030 (change in thousands rel. to Baseline)

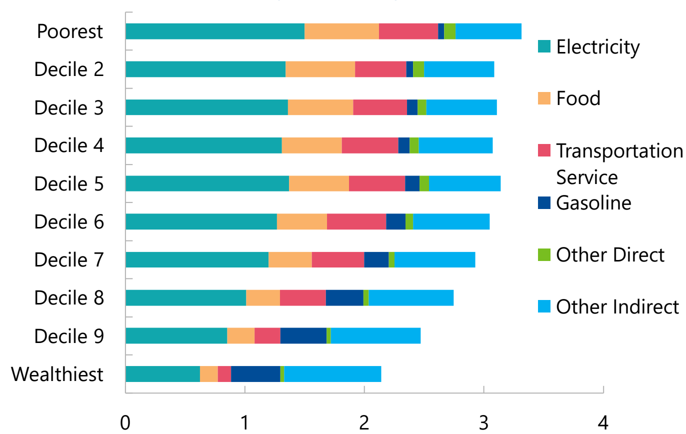


Source: IMF-ENV

20. The significant reallocation of employment across sectors warrants careful policy planning. Overall, total employment in South Africa can increase by about ½ percent relative to the baseline (or roughly 70–90 thousand more jobs) driven by increased employment in the collective, business, and other services (Figure 11B). Relative to baseline, employment falls in fossil extraction and transport services, both of which heavily rely on the contracting fossil sectors. Total employment in the power sector increases with solar and wind sectors driving the growth. The total reduction in fossil electricity is almost entirely driven by coal powered electricity. The model simulation results suggest significant employment turnover consistent with the profound sectoral shift from the transition. In total, job reallocation estimates (i.e., the sum of job destruction and creation) are about 10–17 percent higher on average under the NDC scenarios compared to the baseline over the model simulation period (2022–30). Mitigating the impact on the affected workers and communities is therefore necessary for the decarbonization to succeed. This would require efforts to promote labor market flexibility and build human capital to support displaced workers and prepare the young.[12]

21. The impact of higher carbon pricing on South African households could be regressive. Under the current tax proposal scenario (i.e., $30 per ton by 2030), the CPAT simulation results show that the burden on South African poorest households is over 3.3 percent of consumption, while the estimate is about 2.1 percent for the wealthiest group (Figure 12). The main items behind the impact of higher carbon pricing are increased prices of electricity, food, and transportation (1.2 percent, 0.4 percent, and 0.4 percent of consumption respectively), of which the impact tends to be higher for lower income households. In contrast, the impact from gasoline prices and other indirect effects driven by increases in the price of general consumption goods due to higher energy costs industries appear to be progressive.

Figure 12. Average Effect on Consumption Deciles from Increasing CO2 Price to $30 per ton, 2030
(In percent)



Source: IMF Staff calculations.

Note: The effect estimates measure the loss in consumption in percent of total initial household consumption by household income decile.

E. Use of Carbon Tax Revenues

22. Carbon tax revenues could provide fiscal space to promote economic growth and support the green transition. Similar to other environment-related taxes, carbon tax revenue is not earmarked, which helps preserve flexibility in the budget process. That said, carbon tax revenue will provide room for fiscal support to facilitate the decarbonization transition by expanding the available resource envelope. In the past, some of the revenue from the electricity generation levy was used to fund energy saving measures such as solar water heating, and road rehabilitation from the damage caused by the coal transportation for electricity generation. Under the current carbon tax design, the revenues can be used for an energy efficiency savings tax

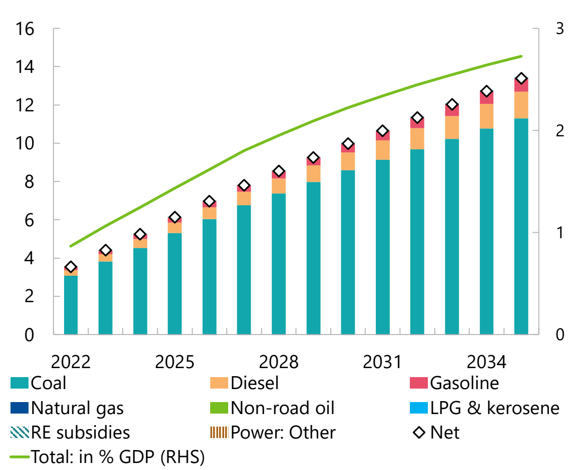
[12] IMF (2022).

incentive, support for the installation of solar water heaters, enhanced free basic electricity/energy for low-income households, improved public transport, and support for a shift from road to rail freight transport.

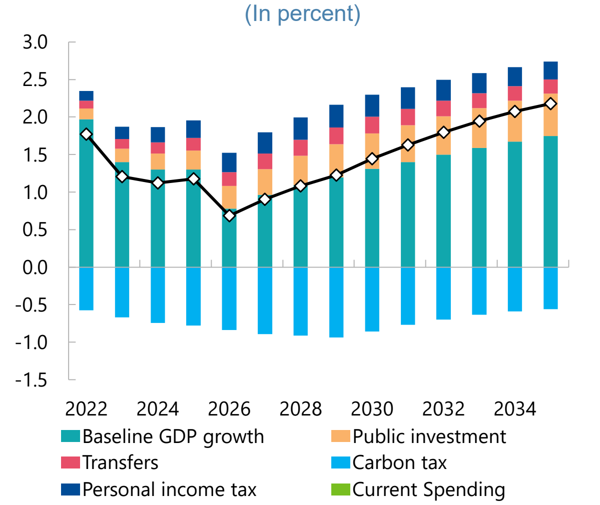
23. Fiscal support could greatly mitigate the near-term adverse economic and distributional effects of higher carbon prices. For illustration, the CPAT model is used to simulate the implications of carbon tax revenue recycling. The analysis assumes that the revenues from the current tax proposal (i.e., \$30/tCO2 by 2030) is utilized toward an increase in climate-smart public investment, a reduction of the personal income tax, and providing cash transfers to vulnerable households. The results suggest that the carbon tax revenues could reach about 2 percent of GDP by 2030, with the bulk of the revenues coming from tax collected on coal consumption (Figure 13A). Recycling the revenues would result in net annual GDP growth of 1.4 percent in 2030 (compared to 1.3 percent in the baseline) and 2.2 percent growth in 2035 (compared to 1.7 percent in the baseline). Figure 13B shows the decomposition of the revenue recycling effects on GDP growth under the current carbon tax proposal scenario. Nevertheless, it is important to maintain the current practice of avoiding earmarking carbon tax revenues to ensure spending efficiency and fiscal transparency in the budget process.

Figure 13. Carbon Tax Revenue Recycling

A. Total Revenue from Carbon Tax
(Real 2021 US \$bn)



B. Economic Growth Impact of Revenue Recycling
(In percent)



Sources: CPAT, IMF Staff calculations.

Note: The simulation results are based on the carbon tax rate increasing to \$30 per ton of CO2e by 2030 as in the current tax proposal. Revenue recycling assumes 30% of revenue is used toward labor tax reduction, 40% for climate-smart public investment, and 30% for cash transfer targeting low-income households. Consistent with the rest of the paper, the results assume no tax-free allowance and exemptions.

24. The use of carbon tax revenue should also consider South Africa's already-substantial social assistance spending and lack of fiscal space. It is necessary, as part of a just decarbonization transition, to mitigate the impact on vulnerable households of phasing out the use of net carbon-emitting technologies and processes. However, South Africa's social assistance spending is already high relative to emerging market and other comparator countries.[13] This notably reflects the country's very high inequality and poverty rate, but also suggests that the social assistance system could be reformed to reflect priorities under the green transition. As is the case with any other budget priority, the use of fiscal resources to support the climate transition should compete with all other budget priorities and be mindful of the available resource envelope. South Africa's lack of fiscal space, heavy debt burden, and large investment needs make a case for a balanced act regarding the

[13] 2021 South Africa Article IV Staff Report, Annex I.

use of the revenue from environmental taxes, which takes into account other budget priorities, including the need to reduce the budget deficit and ensure public finance sustainability.

F. Concluding Remarks

25. To meet South Africa's ambitious climate objectives, a comprehensive and well-designed carbon pricing scheme needs to play a more prominent role in supporting the country's green transition. This paper provides a framework to assess the impact of planned carbon tax policy relative to the country's NDC targets. The distributional analysis also illustrates the costs of climate mitigation across industries and income groups of South African households.

26. There is a need to improve the effectiveness of carbon tax policy in South Africa. The generous tax-free allowances and exemptions under the carbon tax should be phased out in due course. The carbon tax rate in combination with other complementary policy instruments should be aligned with the GHG emission reduction targets. Furthermore, steady implementation of the energy sector reforms to streamline regulatory burden and foster competition will strengthen the effectiveness of the carbon tax by increasing the price-responsiveness of fossil-fuel use.[14]

27. Channeling fiscal resources to support the transition and advancing structural reforms could greatly mitigate the near-term economic and distributional impacts of higher carbon prices. Increasing climate-smart public investment, reducing labor taxes, and/or providing transfer to vulnerable households could facilitate the transition by promoting economic growth. Considering the distributional effects of the carbon pricing impact on South African households, well-targeted support to most affected groups will be important to ensure the success of the transition. While revenue from the carbon tax could facilitate the energy transition, limited fiscal resources and significant investment needs mean that difficult choices will have to be made. Meanwhile, advancing reforms to foster product market competition, promote labor market flexibility, and build human capital, will facilitate the sectoral reallocation of labor and capital, which is key for the success of South Africa's climate mitigation policy.

[14] E.g., IMF (2022).

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Appendix I. Brief Description of the IMF-ENV CGE Model

1. The IMF-ENV model[1] is a recursive dynamic neoclassical, global, general equilibrium model, built primarily on a database of national economies and a set of bilateral trade flows. The model describes how economic activities and agents are interlinked across several economic sectors and other countries or regions. The central input of the model is the data of the Global Trade Analysis Project version 10 database (Aguiar and others 2019). The database includes country-specific input-output tables for 141 countries and 65 commodities and real macro flows. It also represents world trade flows comprehensively for a given starting year. The currently used version (v10) is based on data from 2014. The model describes activities of the key actors: representative firms by sector of economic activity, a regional representative household, a government, and markets. Firms purchase inputs and primary factors to produce goods and services, optimizing their profits. Households receive the factor income and in turn buy the goods and services produced by firms; household demands result from standard welfare optimization under households' budget constraints. Markets determine equilibrium prices for factors, goods, and services. Frictions on factor or product markets are limited, except as described below.

2. The model is recursive and dynamic: it is solved as a sequence of comparative static equilibria. The fixed factors of production are exogenous for each time step and linked between time periods with accumulation equations, like the dynamics of the Solow growth model. Output production is implemented as a series of nested constant-elasticity-of-substitution functions to capture the different substitutability across all inputs. International trade is modeled using the so -called Armington specification, which posits that demands for goods are differentiated by region of origin. This specification uses a full set of bilateral flows and prices by traded commodity. In contrast to intermediate inputs, primary factors of production are not mobile across countries. Model closures assume real government expenditure and nominal current account to be constant to baseline values. Assumptions made on trade closure rules can impact results for export shares of countries in global trade and trade balances for both surplus and deficit countries (Bekkers and others 2020). In the baseline, the values of regional current-account-to-GDP ratios and total foreign-savings-of government-to-GDP ratios are calibrated to projections from ENV-Linkages and thus, for consistency, the same closure rules are retained in IMF-ENV.

3. While the capital market is characterized by real rigidities, the labor market is not. One major characteristic of the model is that it features vintage capital stocks in such a way that a firm's production structure and a firm's behavior are different in the short and long term. In each year, new investment is flexible and can be allocated across activities until the return to the "new" capital is equalized across sectors; the "old" (existing) capital stock, on the contrary, is mostly fixed and cannot be reallocated across sectors without costs. As a consequence, short-term elasticities of substitution across inputs in production processes (or substitution possibilities) are much lower than in the long term and make adjustments of capital more realistic. In contrast, labor (and land) market frictions are limited: in each year, labor (land) can shift across sectors with no adjustment cost until wages (land prices) equalize, and the labor (land) supply responds with some elasticity to changes in the net-of-taxes wage rate (land price).

4. The model also links economic activity to environmental outcomes. Emissions of greenhouses gases and other air pollutants are linked to economic activities either with fixed coefficients, such as those for emissions from fuel combustion, or with emission intensities that decrease (nonlinearly) with carbon prices—

[1] See Chateau et al (2022) and Black et al (2022) for recent applications of the model.

marginal abatement cost curves. This latter case applies to emissions associated with non-energy-input uses (for example, nitrous oxide emissions resulting from fertilizer uses) or with output processes (like methane emissions from waste management or carbon dioxide emissions from cement manufacturing). In the very long term, the model may overestimate the cost of decarbonization, since it does not take into account radical technology innovations that could materialize at this longer horizon (hydrogen, second generation of nuclear and biofuel technologies, carbon capture and storage technology). While some of these new technologies are at an experimental stage, it is difficult to include them in the model at the moment because of a lack of information about the future costs of these technologies if they were deployed at industrial scale.

5. **The model can be used for scenario analysis and quantitative policy assessments.** For scenario analysis, the model projects up to 2050 an internally consistent set of trends for all economic, sectoral, trade-related, and environmental variables. In this context, the model can be used to analyze economic impacts of various drivers of structural changes like technological progress, increases in living standards, and changes in preferences and in production modes. A second use for the model is quantitative economic and environmental policy assessment for the coming decades, including scenarios of a transition to a low-carbon economy. In this case, the model assesses the costs and benefits of different sets of policy instruments for reaching given targets like greenhouse gas emission reductions. With the recursive dynamic framework of IMF-ENV, in a carbon pricing policy simulation, for example, the model considers not only the direct effects of changes in relative prices of the carbon-intensive fuels but also the second-round effects of the policy on investment and labor over time. Moreover, the model projects the structural changes resulting from the policy over time by differentiating the elasticity of substitution between labor and capital-energy over the short term and the long term (less elastic in short term but more elastic in long term). There are various upside and downside risks around estimated GDP effects. For example, on the upside, new rapid technological innovations or more learning by doing could reduce the costs. On the downside, stranded assets, and a difficult reallocation of labor across sectors could increase the costs. Additional risks might affect abatement costs to stay within the temperature goals of the Paris Agreement positively or negatively, including economic and population growth and strategies used by fossil fuel producers.