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ESTIMATING THE ECONOMY-WIDE AND REDISTRIBUTIVE IMPACTS OF MITIGATION IN SOUTH AFRICA

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TSITICA Transforming Social Inequalities Through Inclusive Climate Action
ARUA-CD Centre of Excellence Climate and Development
UK Research and Innovation
ACDI African Climate & Development Initiative
University of East Anglia
ACEIR African Centre of Excellence for Inequality Research

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Estimating the Economy-wide and Redistributive Impacts of Mitigation in South Africa

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DISCLAIMER

All opinions, interpretations and conclusions expressed in this Transforming Social Inequalities through Inclusive Climate Action (TSITICA) Working Paper are entirely those of the authors and do not reflect the views of the research funder UK Research and Innovation (UKRI).

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The Transforming Social Inequalities Through Inclusive Climate Action (TSITICA) project investigates how climate change action can be socially transformative in three contrasting African countries: Ghana, Kenya and South Africa. The research agenda addresses the nexus between climate change, sustainable livelihoods and multidimensional poverty and inequality to tackle the overall question: how can climate actions be deliberately targeted to improve livelihoods and lead to equitable benefits for the most vulnerable and poor – especially for women and youth? With the goal of inspiring climate actions that also reduce poverty and inequality, based on evidence and insights from the research, TSITICA aims to contribute the Agenda 2030 ambition of leaving no one behind.

The full project team comprises researchers from two African Research Universities Alliance (ARUA) Centres of Excellence hosted by the University of Cape Town (UCT); researchers from the centres' regional nodes at universities in Ghana and Kenya; and collaborators from four universities in the United Kingdom:

• African Centre of Excellence for Inequality Research, hosted by UCT's Southern Africa Labour and Development Research Unit, School of Economics

• ARUA Centre of Excellence in Climate and Development, hosted by UCT's African Climate and Development Institute

• ARUA-CD and ACEIR nodes convened respectively by the Institute for Environment and Sanitation Studies and the Institute of Statistical, Social and Economic Research, University of Ghana

• ARUA-CD and ACEIR nodes convened respectively by the Institute for Climate Change and Adaptation and the School of Economics, University of Nairobi

• Grantham Research Institute on the Environment and Climate Change, London School of Economics and Political Science

• Townsend Centre for International Poverty Research, University of Bristol

• International Inequalities Institute, London School of Economics and Political Science

• Tyndall Centre for Climate Change Research, University of East Anglia

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Abstract

South Africa is characterised by high levels of poverty and inequality which make a large proportion of the population vulnerable to climate change. At the same time, the country is one of the largest producers of emissions per capita due to its dependence on fossil fuels. South Africa has committed to the global ambition to reduce emissions. In its Updated Nationally Determined Contribution, South Africa agreed to reduce emissions to between 398-510 Mt CO2-eq and 350-420 Mt CO2-eq. Such a transition requires structural changes in the economy which may have implications for households. This paper builds on previous research assessing the impacts of more ambitious mitigation actions in South Africa. The results show that increasing mitigation targets beyond those achieved under a least cost energy plan negatively affects real GDP, employment, and poverty. These impacts can however be mitigated or offset through climate mitigation financing as this reduces the investment burden otherwise placed on the economy. Failing to mitigate imposes potential costs on the South African economy - these costs could be larger than ambitious emissions reductions without climate financing.

TABLE OF CONTENTS

1. Introduction

South Africa is characterised by high levels of poverty and inequality. The Gini index, a measure of inequality, measured 67 in 2018 and is the highest in the world (World Bank 2022). Poverty levels exceed that of many other middle-income economies with more than 55% of the population living at the national upper poverty line in 2014 and 25% living in food poverty. Poverty is estimated to have worsened since 2015 in light of weak economic growth, rising unemployment and the COVID-19 pandemic reaching 60% in 2020. The high levels of poverty and inequality make a large proportion of the population vulnerable to changes in the climate which under climate change translate into higher temperatures, more erratic rainfall, and an increase in extreme climatic events such as droughts and floods. Recent evidence of this has been seen in the 2015/16 drought which was the worst experienced in the country since 1991/92 and the on-going floods being experienced along the east coast of the country.

At the same time South Africa is one of the largest producers of emissions per capita due to its dependence on fossil fuels, specifically coal and crude oil. To reduce the harmful impacts of climate change, South Africa has committed to the global ambition to reduce emissions. In its Updated Nationally Determined Contribution (NDC), South Africa agreed to reduce emissions to between 398-510 Mt CO2-eq (-4% and -25% relative to 2017) and 350-420 Mt CO2-eq (-21% and -34%) by 2025 and 2030, respectively. Previous studies (Inglesi-Lotz 2016; CSIR 2018; Hartley et al. 2019; Merven et al. 2019, 2020; and McCall et al. 2019) have highlighted that given existing policies and measures implemented by the South African government, along with the least-cost optimisation of energy generation, South Africa would be capable of reaching these targets at minimal cost to the economy. Such a transition, however, does require structural change in the economy which will have impacts on households. Current mitigation commitments are however only to 2030. For global mitigation efforts to limit temperature increases to well below 1.5°C, net emissions need to decrease to zero thus requiring further mitigation actions by all countries including South Africa. Achieving such emissions mitigation will require larger changes in the economy and mitigation in harder to abate sectors which will be more costly.

This paper builds on previous research assessing the impacts of mitigation actions in South Africa (Merven et al. 2021; Merven et al. 2020; and Hartley et al. 2019). It improves on previous studies by using more recent data and more deeply assessing the distributional impacts of climate mitigation actions including its impacts on poverty and inequality. The impacts of climate financing and punitive measures from insufficient action is also explored. Understanding the distributional impacts of mitigation actions can assist in the development of transition policies and the design of mitigation actions such that they achieve the co-benefits of reducing poverty and inequality. The study uses a linked energy-economic model for South Africa and an accounting-based microsimulation module to assess the distributional impacts of mitigation action.

2. Emissions and energy

South Africa is reportedly the 14th largest greenhouse gas emitter in the world and the highest in Africa. In per capita terms, emissions are higher than the global average and those of other developing countries including China and India (Global Carbon Atlas). The largest contributor to emissions is the energy sector which makes up 80% of total emissions. Industrial Processes and Product Use (IPPU), Agriculture, Forestry and Other Land Use (AFOLU) and the waste sector account for 8.6%, 7.5%, 5.9% respectively (see Figure 1). Within energy the power sector, due to its dependence on coal, is the largest emitter. This is followed by the industry sector due to its coal use; and the transport sector in which crude oil and coal based liquid fuels are the primary source of energy.

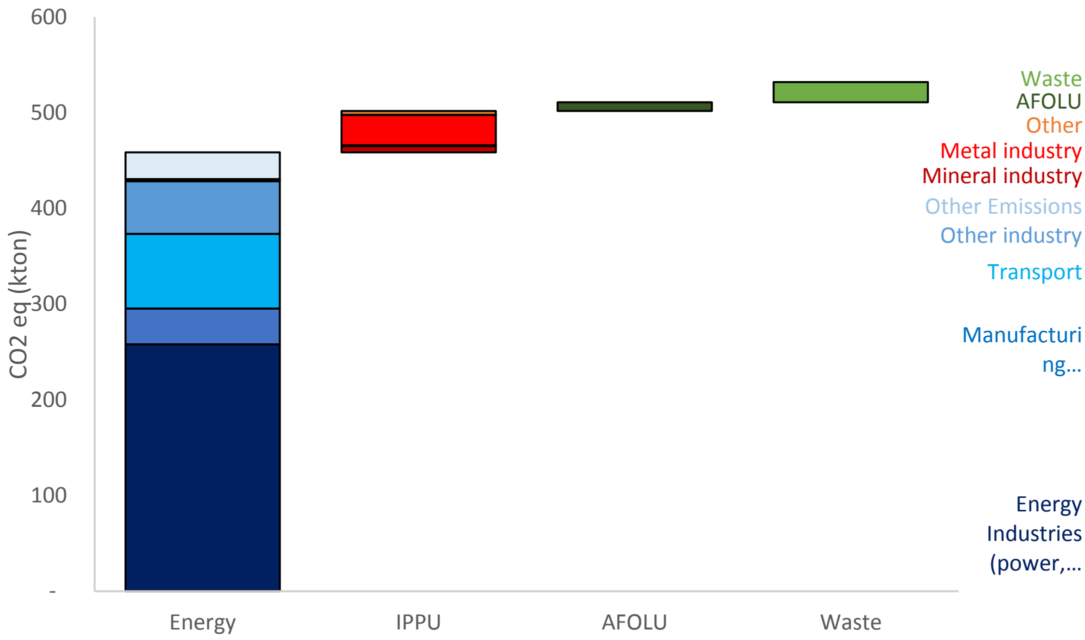


Figure 1: Emissions by IPPC sector, 2017

Source: SATIM

Figure 2 below shows the flow of energy in the South African economy in 2017. As highlighted the bulk of primary energy is provided by coal and crude oil. Apart from crude oil, the bulk of energy is domestically sourced and generated. Other imported fuels include natural gas, liquid fuels, and nuclear fuels. Coal is an important export commodity for South Africa, roughly a third of domestically extracted volumes exported. Other exported energy commodities include refined liquid fuels and electricity. Industry is the largest energy end user with a combination of different fuels consumed including coal, electricity, liquid fuels, and natural gas. Commercial, agriculture and household users primarily use electricity while the transport sector consumes refined liquid fuels.

Coal accounts for 85% of power generation, nuclear 6% and imports 4%. In 2017, variable renewable energy (solar and wind) accounted for less than 5% of total power generation. Power generation is concentrated in the northern parts of South Africa while renewable energy is focused in the south and western parts of the country, specifically the Northern Cape and Western Cape. Figure 3 presents the solar and wind resource potential in South Africa by region. Liquid fuel generation is primarily through crude oil (65%) and coal to liquid (18%) refining.

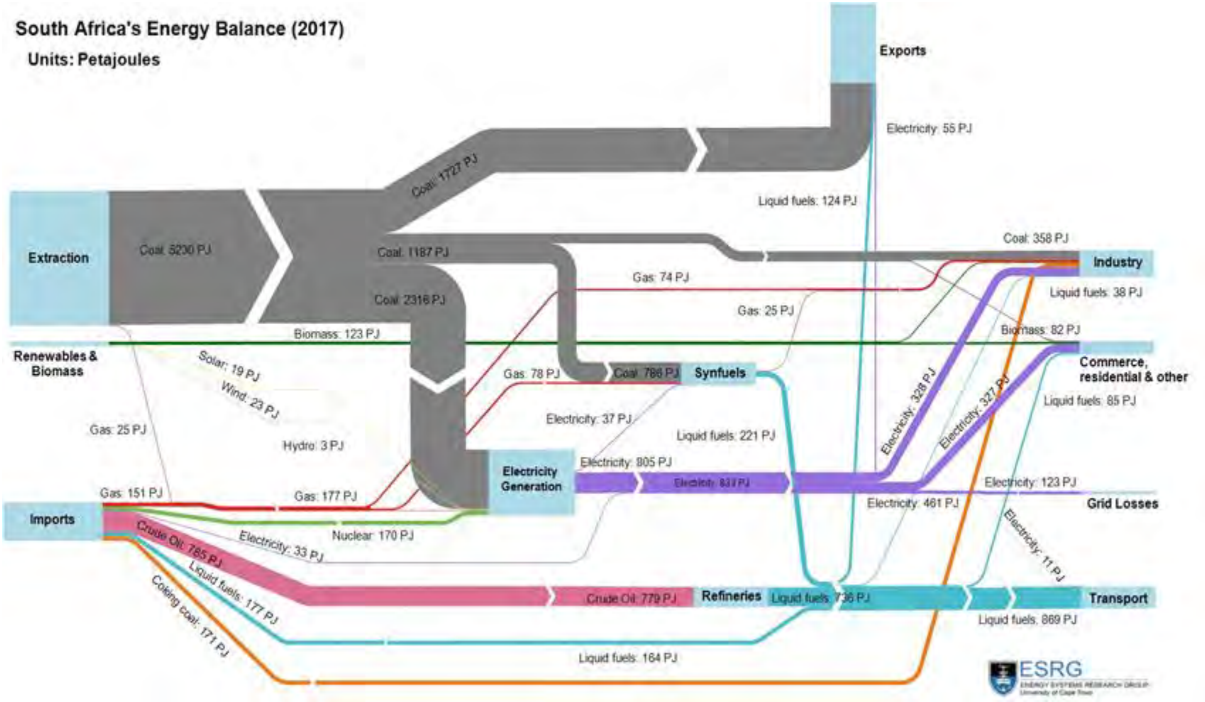


Figure 2: Energy flows in South Africa, 2017

Source: ESRG, UCT

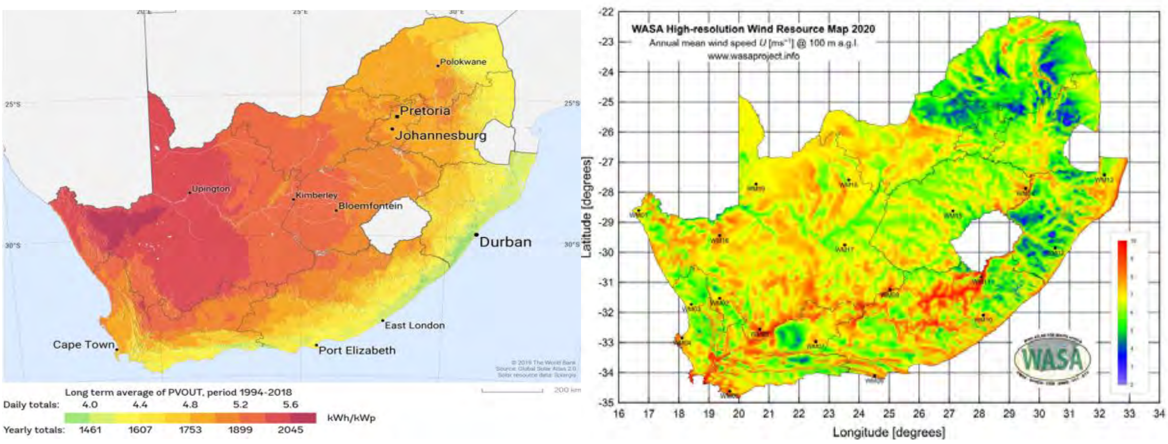


Figure 3: Solar PV potential (left) and wind resource (right) in South Africa

Source: Global Solar Atlas; Wind Atlas for South Africa

3. Perspectives on poverty and inequality in South Africa

The economic performance of South Africa is worse compared to other countries of the same standing in the world. While developing countries on average grew at 5.4% per year between 2010 and 2016, South Africa grew at an average rate of 2.1%. South Africa is classified as an upper middle-income country, but poverty levels are much higher than that of countries of the same rank. South Africa has made progress in reducing poverty since apartheid, mainly through its cash grant transfer programs. However, the same cannot be said about inequality levels which have been on the rise – South Africa is reportedly one of the most unequal countries in the world. Wealth inequality is higher than income inequality. The wealth inequality Gini coefficient stood at 0.93 in 2015 against 0.63 for income inequality (Leibbrandt, Finn and Oosthuizen, 2016; Department of Planning Monitoring and Evaluation, Statistics South Africa and The World Bank Group, 2018; Francis and Webster, 2019).

Central to the slow economic growth, high poverty and high inequality levels story is the high level of unemployment. The unemployment rate rose from 20% in 1994 and stood at 27.7% in 2017 (Leibbrandt, Finn and Oosthuizen, 2016; Statistics South Africa, 2017; Francis and Webster, 2019). According to Bhorat et al. (2016), the unemployment rate in the first income quintile is 61.2% compared to 3.3% in the fifth income quintile. Wage inequality also makes up the largest component of total inequality. The wages of high-income quintile earners are about 39 times that of earners in the poorest income quintile. This is mainly attributed to differences in education. Households with no employed individuals are also more likely to be poor (Bhorat et al., 2015; Finn, 2015).

The current poverty and inequality picture in South Africa is highly influenced by the legacy of apartheid. The African sub-population had the highest proportion of people classified as poor (70.75%) in 2015 compared to 56.8%, 20.5% and 4.1% of the Coloured, Indian/Asian and White sub-populations, respectively. The poverty rates are highest in rural areas (59.7% in 2015) and in the Eastern Cape, KwaZulu Natal and Limpopo provinces. The sub-national distribution of inequality and poverty is largely inherited from the apartheid era as these provinces had the highest concentration of Homelands/Bantustans, areas reserved for the African population, and which were characterised by poor service delivery and infrastructure (Finn, 2015; Department of Planning Monitoring and Evaluation, Statistics South Africa, and The World Bank Group, 2018).

The COVID-19 pandemic made an already bad situation worse. Loss of employment and adverse health are some of the negative shocks that make households vulnerable to poverty. Employment was reduced by 40% during the lockdowns in the COVID-19 pandemic. Approximately 20-33% of the individuals who lost their jobs fell into poverty thus adding to the pre-existing inequalities. The COVID-19 policies implemented by the government however went a long way in cushioning households from the impacts of the pandemic (Jain et al., 2020; Barnes et al., 2021; Shifa, David and Leibbrandt, 2021)

3.1 Climate change, poverty, and inequality

Climate change is a phenomenon that cannot be ignored in the current realities of today's world. While the effects of climate change affect everyone regardless of their socioeconomic status, the poor are more disadvantaged since climate change further exacerbates existing vulnerabilities. The negative impacts of climate change on health, food security and access to safe drinking water are worse for the poor who are not able to adapt. Housing conditions of the poor are also more likely to be affected by extreme weather conditions such as flooding (Abeygunawardena *et al.*, 2010; Winsemius *et al.*, 2018). According to Islam and Winkel (2017), existing inequalities place the poor at a disadvantage which makes them suffer the adverse effects of climate change more which further aggravates existing inequalities thus forming a vicious cycle between climate change and inequality. Three channels explain this phenomenon. First, the poor are more exposed to the adverse effects of climate change, secondly, they are more susceptible to the ensuing damage and lastly, their ability to bounce back after experiencing the devastation caused by negative climate shocks is severely limited.

In terms of exposure, location and occupation are the key determinants. The poor are more likely to live in areas which are prone to climatic shocks since they cannot afford to live in safer areas. There exists a positive relationship between temperatures and household wealth in cold areas and an inverse relationship in warm areas. This means that the poor are more exposed to the extremities of weather. The poor are more likely to live in low-lying areas which are prone to flooding. The poor are also more likely to live in drought-prone areas. A larger proportion of the poor live in rural areas and depend on agricultural production, poor rainfall is especially detrimental to their livelihood. Low agriculture production threatens food security since it results in increased food prices which are disastrous to the poor whose food expenditure takes up a sizable proportion of their income. Occupations which require one to be outside more are mainly concentrated among the low-income groups thus making them more exposed to adverse climatic shocks (Islam and Winkel, 2017; Park *et al.*, 2018; Winsemius *et al.*, 2018; Jafino *et al.*, 2020).

Susceptibility implies that even with the same exposure, the poor are still worse off when adverse climate events happen. Their housing conditions are more prone to damage by the elements and the health risks associated with extreme weather. Water-borne diseases such as diarrhoea affect the poor more in the event of a flood since they lack access to piped water and thus end up drinking unsafe water. They are also unable to meet the expense of alleviating extreme heat. The inability to diversify their investments also means that they end up losing most if not all their livelihood if an extreme weather event happens. These negative health effects also end up affecting individual productivity and incomes thus sinking them further into poverty (Hallegatte *et al.*, 2016; Islam and Winkel, 2017).

The poor have a lower ability to cope and recover from climate shocks. They are not able to pay for insurance that will cushion them in the event an adverse climate shock wipes out their assets and source of livelihood. They also lack health insurance which results in the poor selling off their assets to pay for the cost of treatment of health issues triggered by adverse climate. Since the rate of recovery is slower for the poor compared to the non-poor, the inequalities after a climate shock are much higher since the poor are now worse off (Islam and Winkel, 2017).

Jafino *et al.*, (2020) estimate that without climate change, the number of people living in extreme poverty will be 313.5 million people, most of whom will be in sub-Saharan Africa (SSA) and South Asia. While this is far from the zero-poverty target envisaged in the sustainable development goals, it is approximately half the 2015 global poverty headcount. Under climate change an additional 38 to 100 million people would fall into extreme poverty. The range represents the uncertainty related to climate change impacts with the smallest number presenting the most optimistic case and the larger the most pessimistic. The rise in poverty will be concentrated in households in SSA and South Asia. Azzari and Signorelli (2020) find that in SSA a 1-in-50-year type flood shock would result in a 35% decrease in total and food per capita consumption and increase extreme poverty by 17 percentage points. Studies estimating the impact of climate change in South Africa show that the country is likely to be negatively affected by climate change with some regions more vulnerable than others (see Cullis et al., 2015; Hartley et al., 2021). These regions tend to overlie those already home to many vulnerable households.

Poverty places poor people at a higher risk of experiencing the negative effects of climate change. Climate change on the other hand also increases the risk of individuals falling into poverty or further aggravating existing poverty levels. The use of social safety nets and universal health care are recommended as a means of cushioning the poor from the negative impacts of climate change. In the long run, emission reduction policies are recommended to reduce the impacts of climate change. However, governments need to ensure that they cushion the poor against the cost of climate mitigation policies (Hallegatte *et al.*, 2016).

3.2 Mitigation, growth, and poverty

The impact of mitigating climate change often tends to spill over to the economy through changes in employment, poverty, and food security. Climate mitigation policies such as carbon taxes imposed to curb emissions are expected to increase production costs, which translates to higher output prices, lower real wages, and lower incomes. Employment levels depend on production levels. Therefore, an increase in production in sectors using renewable energy results in increases in labour demand and vice versa. At the same time, carbon emission regulations are bound to affect the transport of foods which impacts negatively on food security (Wlokas, 2008; Klausbruckner et al., 2016; van Heerden et al., 2016; Nong, 2020; Merven et al., 2021). Thus, for a country such as South Africa which has the highest inequality levels in the world, the repercussions of interventions to reduce GHG emissions on households and the economy at large must be considered. Various authors have researched the economic impacts of climate change mitigation.

3.2.1 South African studies

Several studies have assessed the impact of mitigation in South Africa. These have focused on assessing the macroeconomic impacts under either an emissions constraint or through the implementation of a carbon tax.

Merven et al., (2021) assess the economic costs associated with climate mitigation at varying levels of ambition using a linked energy-economic model. The results from their analysis find mitigation ambition that limits emissions up to 8GT has a small negative effect on economic growth and employment. Beyond this point, the impact of more ambitious mitigation become increasingly more costly per ton of emissions mitigated. The authors however highlight that increasing energy efficiency in line with government policies and measures can partially offset this impact as the demand for energy is lower. Altieri et al. (2016) uses a similar approach to explore the effects of meeting an energy carbon constraint of 14GT on the economy. They find that in the long run with incentivizing growth in sectors with low-carbon emissions and high levels of labour absorption or improvements to education and training to increase the level of high skilled labour into the economy South Africa can achieve multiple climate and development objectives including a reduction in greenhouse gas emissions, increase in GDP per capita and decrease in energy poverty. The decline in energy poverty is the result of higher household income from increased employment as the economy structurally shifts toward low-carbon labour-intensive sectors such as agriculture.

Nong (2020) uses a CGE model to assess the impacts of a carbon tax in South Africa. The results from the study showed that the economic impacts of imposing a carbon tax is small relative to the gains in emissions achieved. The study considered a carbon tax of US$9.15/ton of CO_2eq, real GDP was between 1.2% and 1.6% lower while emissions decreased by between 12% and 16%. The study does identify structural changes in the economy with fossil-based industrial sectors negatively affected.

Van Heerden et al. (2016) using a dynamic CGE model also showed the effect of carbon taxes on growth to be negative. However, the extent of the effect depends on how carbon tax revenues are recycled back into the economy. Production-targeted recycling of taxes through subsidies into the economy has the lowest negative effect as opposed to consumption-targeted recycling.

Van Heerden et al., (2006) evaluated the effect of imposing taxes on GHG emissions, fuel, electricity use and energy on households and industry in South Africa and thus raising revenue in the process. They used a CGE model for analysis. The channels through which these taxes are recycled to the households and industries are by giving a tax break to labour and capital, giving an indirect tax break to households, and reducing the prices of food. The study finds that reducing food prices using the revenues raised from the environmental taxes had an effect of reducing poverty and spurring economic growth while achieving the goal of reducing emissions.

3.2.2 Studies from the rest of the world

Zhao *et al.*, (2022) investigate the impact of carbon pricing on poverty and inequality in China between 2010 and 2050 using Integrated Assessment Models (IAMs). While carbon pricing is found to be effective as a mitigation strategy, it also has a negative effect since the increase in food and energy prices disproportionately affects the poor. Greenhouse gas emissions increase up to the year 2030 after which they decline. However, carbon pricing is also accompanied by GDP losses. While poverty alleviation strategies are still effective in reducing poverty, the rate of reduction is much lower due to the regressive nature of carbon taxes which has relatively larger negative effects on the poor. They recommend exempting poor households from the carbon tax and subsidising food and energy consumption to cushion the poor from the regressive impacts of carbon taxes. Nong and Simshauser (2020) use a general equilibrium model to analyse the impact of carbon taxes. They find that this results in a reduction in emissions and

GDP. Emission-intensive sectors incur additional costs and reduce output which ultimately has a negative impact on labour demand. However, when renewable development and technology growth is incorporated into the model, the carbon emissions reduce even more and the negative impact on GDP is dampened.

Fujimori, Hasegawa and Oshiro (2020) use an integrated assessment model to assess whether carbon taxes can be used in poverty alleviation. Current projections show that global poverty will have halved from the 736 million observed in 2015 to 360 million in 2030 and further decreased to 91 million in 2050. Climate mitigation policies are expected to reduce income and increase energy and food prices by 2%, 7.5% and 4.4% respectively. This burden falls disproportionately on the poor. While revenue raised from carbon taxes can be channelled towards poverty eradication, low-income countries are not likely to benefit since they have fewer emissions thus reducing the potential to raise revenue from carbon taxes. Dorband *et al.* (2019) use microsimulations on existing subsidy and tax data to assess the distributional effects of carbon pricing in low and middle-income countries. They show that carbon taxes increase the tax burden thus reducing the disposable income available. They also show that taxes have a positive relationship with per capita incomes, i.e., taxes are especially regressive in richer countries. Energy products are more carbon-intensive compared to food, goods and services and this has an effect on the distributional effects of carbon pricing. Since the lower-income groups spend a larger proportion of their income on food, carbon pricing tends to be progressive in lower-income countries

Campagnolo and Davide (2019) investigate the trade-offs that exist between emission reduction policies and the SDG goals of eradicating poverty and reducing income inequality using intertemporal CGE models. They find that the imposition of mitigation policies has a heterogenous effect on poverty and inequality. Countries with lower carbon taxes experience economic growth due to increased competitive advantage. However, inequality in these countries is also high. Countries with stringent mitigation policies experience an increase in the agriculture share and industry share which serves to reduce inequality. Poverty reduction slows down, especially in countries with more stringent conditions which results in higher mitigation costs. In countries where the economic gains outweigh increases in inequality, the overall level of poverty reduces. The inclusion of a green climate fund (GCF) transferring money from developed countries to developing countries lessens the negative impact of climate mitigation policies.

Fujimori et al. (2019) assess the impact of climate mitigation on food security through integrated assessment models (IAMs). They found that the number of people at risk of hunger rises when carbon prices are set to maintain temperature increase at a capped level of 1.5 -2°C compared to pre-industrial levels. High carbon prices trigger an increase in agricultural prices resulting in an increased risk of hunger. Dennig *et al.*, (2015) use a Regional Integrated model of Climate and the Economy (RICE) to assess the social cost of carbon emissions and the economic inequalities of the climate change impacts between the years 2000 and 2200. They show that the future negative impacts are especially skewed toward the lower end of the income distribution. The poorest income quintile bears the largest burden of climate change which results in a decline in per capita consumption over time. Callan et al. (2009) use a SWITCH model to evaluate the impact of recycling carbon taxes on household income distribution in Ireland. They show that recycling taxes mainly benefits households at the lower end of the income distribution through increased welfare payments.

4. Climate policy in South Africa

In line with global standards, South Africa has developed several policies to inform climate actions over time. This is illustrated in Figure 4 which shows a timeline of key policies developed over the last decade. One of the key documents related to climate change actions and commitments is the Updated Nationally Determined Contributions (NDC, RSA 2021). The Updated NDC outlines the country's mitigation commitments and support needed for achieving these and reflects the country's first adaptation communication. The document builds on previous policies including the South African National Climate Change Adaptation Strategy (NCCAS) which is the country's national adaptation plan (DFFE 2020). The NDC Update highlights and quantifies the focus areas for adaptation policy in South Africa, including adaptation governance and legal frameworks (US$13 billion); research into climate impacts, risks and vulnerabilities, and the development of appropriate tools (US$8 billion); the implementation of NCCAS adaptation interventions (US$3-4 billion); and enabling the access to adaptation financing; stocktaking existing and past national and provincial efforts. Adaptation financing requirements are estimated to be between US$16-267 billion over the 2021 to 2030 period.

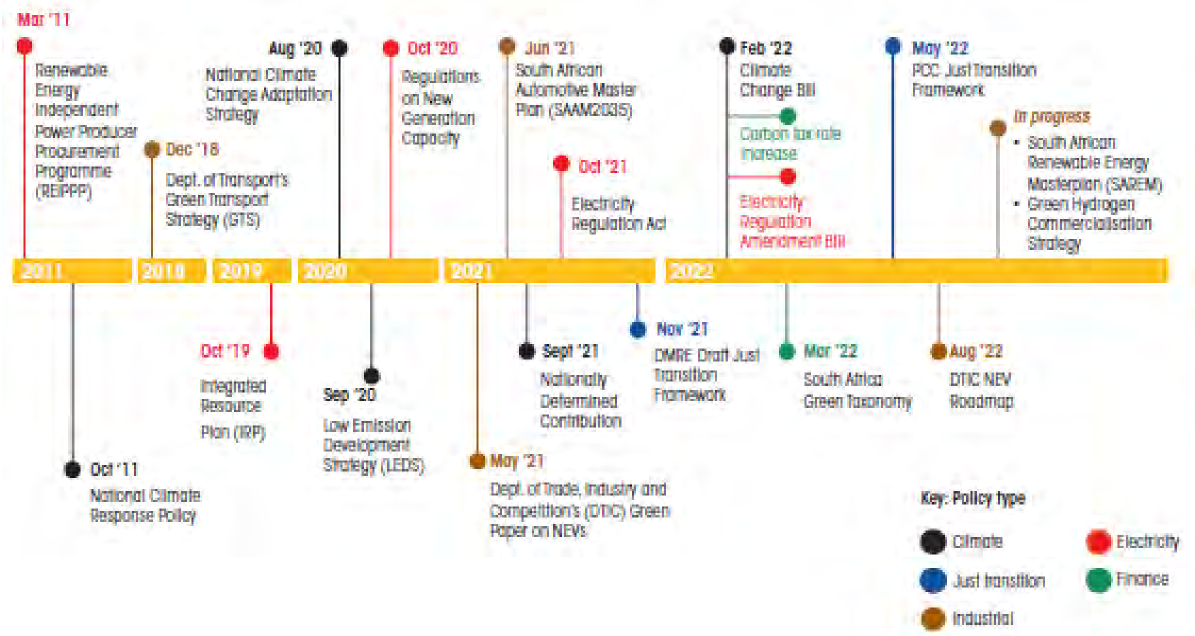


Figure 4: Timeline of key climate action policies in South Africa

Source: The Presidency, 2022

The South African Updated NDC commits to reduce national emissions to between 398-510 Mt CO2-eq (-4% and -25% relative to 2017) and 350-420 Mt CO2-eq (-21% and -34%) by 2025 and 2030, respectively. Figure 5 presents the Updated NDC commitment (dark blue area) relative to the Intended Nationally Determined Contribution peak, plateau and decline emissions trajectory (light blue area). The lower band of the Updated NDC falls within the September 2020 Climate Action Tracker (CAT) estimate for a 2-degree world but is still well above 1.5-

degree estimates. While the Update NDC commitments only reach 2030, the document does reflect the country's voluntary commitment to a goal of net zero carbon emissions by 2050 as communicated through the Low Emissions Development Strategy (LEDS, DEFF 2020). This goal however as highlighted in the LEDS must be achieved in a 'just' manner.

For South Africa to reach its Updated NDC commitments foreign financial assistance is needed. The Just Energy Transition Investment Plan estimates that for a 'just' energy transition R1.5 trillion is needed for investment between 2023 and 2027 to achieve the lower bound of the Updated NDC (see Figure 6). While part of this funding, R128 billion (US$8.5 billion) has been pledged by the International Partners Group (IPG), a large funding gap remains. The Presidency (2022) indicates that further funding will achieve the 'just' transition goals over time.

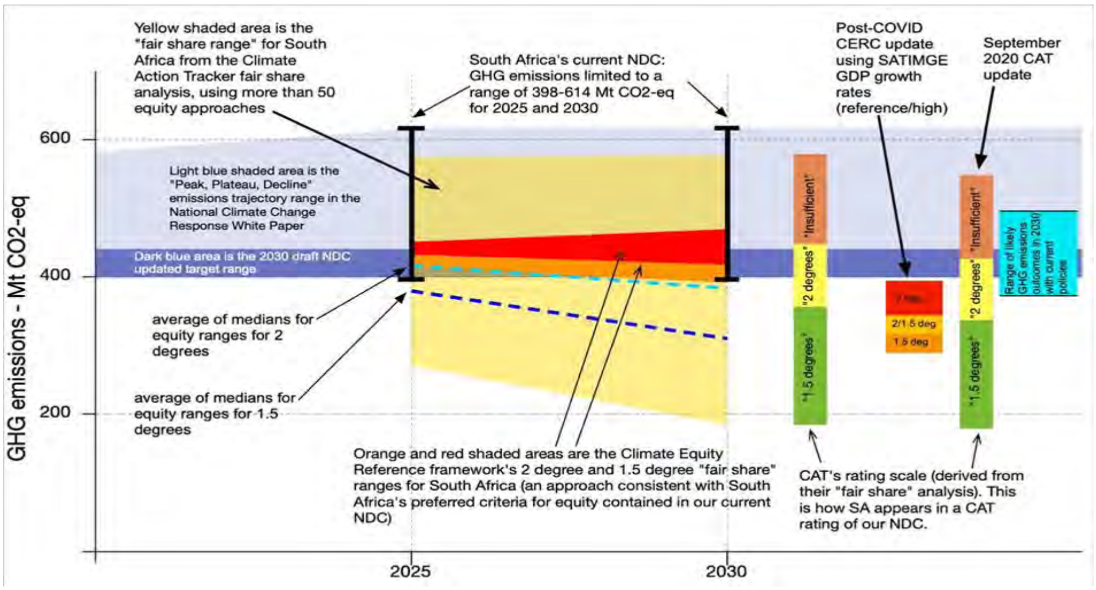


Figure 5: South Africa's "fair share" equity lens for the NDC update, 2025 and 2030, with updated "fair share" CAT (post September 2020) and CERC (May 2021) ranges

Source: ESRG, 2021

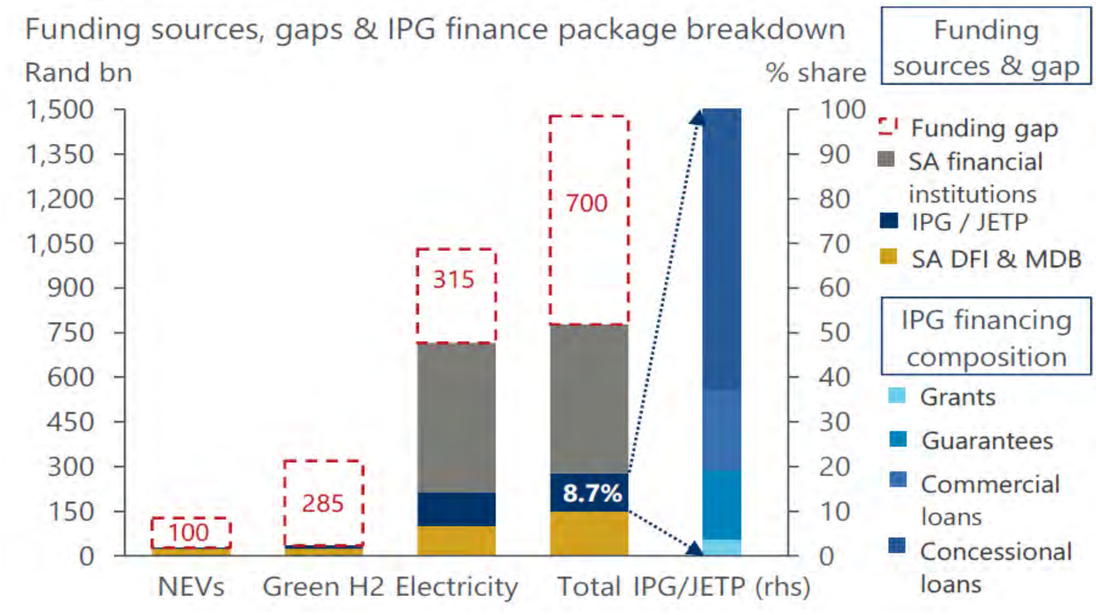


Figure 6: Just Transition financing needs, 2023-2027

Source: Oxford Economics Africa, 2022 (adapted from The Presidency 2022)

5. Framework for quantitatively assessing climate action impacts

The distributional impacts of climate actions in South Africa are assessed using a linked energy-economic model for the country with outputs linked to an accounting-based microsimulation module for poverty and inequality estimations (see Figure 7). The linked model, referred to as SATIM-GE, is a modelling framework in which two individual models, namely the South African Times (SATIM) model and an energy extended version of the South African General Equilibrium (e-SAGE) model, are hard-linked through the iterative exchange of information (see Merven et al. 2020). Such an approach is well placed for climate action analysis as the combination of the detailed models ensures that the physical properties of the energy system are accounted for and thus that the appropriate costs and constraints are considered, but also that the economic impact of changes in the energy system are assessed and their implications for energy demand are fed back into the planning of energy capacity. The SATIM-GE model is also linked to spreadsheet-based models of the AFOLU and waste sectors to account for total emissions in the country.

The SATIM model is a least-cost bottom-up full sector engineering energy optimisation model that includes both the supply side (i.e., fuel and technology options) and demand side (i.e., energy demand by use). The model includes existing and committed energy capacity, and a range of viable technology options to meet future demand which is modelled by end use for each sector in the SATIM model. The model is calibrated with 2017 base year data from the DMRE's energy balances, the National Inventory Report, and other sources. Merven et al. (2019) provides a fuller description of the SATIM model and Marquard et al. (2021) provides more detail on the underlying model assumptions and calibration.

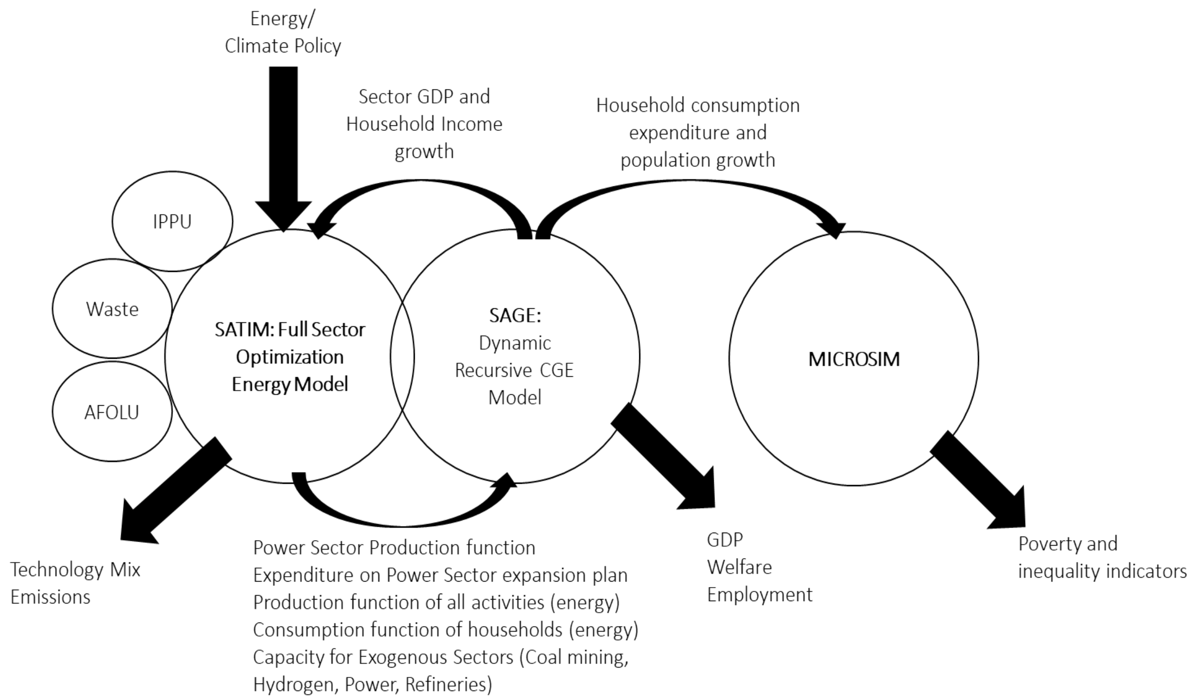


Figure 7: Illustration of modelling framework

Source: Authors

eSAGE is a dynamic recursive, economywide computable general equilibrium (CGE) model built on the framework from Diao and Thurlow (2012). CGE models are useful simulation tools for distributional policy analysis as they capture the functioning of a market economy in which the interactions of economic agents are mediated via prices and markets, with macroeconomic and resource constraints respected. The model includes detailed information on sector production and intermediate use including factor use. Detailed information on household income and expenditure is also included with linkages to the production sector represented by returns to households for factors of production provided to the market; and expenditure of households on goods and services produced and provided to the market. The general equilibrium framework of the model adjusts prices such that markets are clear. These price changes inform the level of household consumption expenditure. In the case of the linked model, SATIM provides the eSAGE model with the level of consumption for different energy commodities. These linkages enable the impact assessment of changes in the economy on households. The eSAGE model includes 10 representative household groups.

The version of eSAGE used in this analysis uses an enhanced version 2019 social accounting matrix (SAM) for South Africa, developed by Davies and van Seventer (2020), to inform the underlying structure of the economy in the base year. The SAM is enhanced by disaggregating the agriculture, mining, and energy sectors. The agriculture sector is disaggregated to reflect different crop activities and linked to food processing sub-sectors to capture respective food value chains. The underlying data used to inform the disaggregation of the agriculture sector and the links between agriculture commodities and food processing is Phoofolo (2018). The mining and energy sectors are disaggregated to align with SATIM sub-sectors. In the linked modelling framework, SATIM informs the development and production of these sectors over time.

The SAM is hybridised with the same energy information underlying the SATIM model to ensure that the models are consistent. The energy information is also used to extract other energy sub-sectors such as refineries and mining. Appendix A presents the SAM accounts.

A key feature of the eSAGE model used in SATIM-GE is the behaviour of household consumption over time. Most CGE models assume a Linear Expenditure System for household expenditure. eSAGE takes a Cobb-Douglas approach, changing consumption shares over time in line with changes in household incomes to account for changes in living standards. For example, if incomes in the poorest 10% of households increase to the level of the poorest 20% the consumption shares are adjusted to reflect the profile of households in the poorest 20%. Such an evolution in household consumption is better suited for long term analysis as it better captures the "welfare-enhancing feature of modern economic development" (Chai, 2018). Such an approach is also important for understanding household energy needs as fuel type demands evolve with lifestyle changes. More detail on this approach can be found in Merven, Hartley and Schers (2020).

While the eSAGE model allows for some household distributional analysis through the inclusion of a disaggregated household sector, the household groups in the model are still representative households (i.e., households are an aggregate group of households and not an average household). To extend the distributional analysis of climate actions on households, a top-down micro-accounting approach following Pauw and Thurlow (2011) is taken (see Appendix B). Under this approach economic outcomes from the SATIM-GE modelling framework are soft-linked to a microsimulation module to calculate expenditure-based inequality and poverty estimates. The 2015/16 Living Conditions Survey (LCS), used to calibrate the household development of the 2019 SAM, is used to inform the base year calculations. Each of the households in the survey is linked to the corresponding household group in the eSAGE model through growth in household consumption by commodity group and population resulting in a different per capita level of expenditure per household across time and scenario. This updated information is then used to recalculate inequality and poverty indicators. This approach allows for a refined interpretation of the effects on poverty and inequality although within-group income distributions remain constant and the methodology is unable to account for the dynamics related to persistent poverty and poverty traps (Pauw and Thurlow, 2011). While no behavioural changes are directly modelled in the microsimulation, behavioural changes from the eSAGE model are passed through via relative differences in consumption expenditure growth across commodity groups. The national monthly upper, lower and food poverty lines of R992, R647 and R441 (updated to 2019 Rands and annualised) from the 2014/15 LCS is used in the microsimulation module.

5.1. 2019 SAM Economic Structure

Table 1 presents the broad economic structure of production in South Africa according to the 2019 SAM. As illustrated the services sector is the largest producing sector and primary employer in the economy accounting for 68% of total GDP and 72% of total employment. In terms of employment, the sector is a key employer of lower skilled workers employing more than 70% of the primary and middle level educated workforce respectively (see Figure 8). Apart from transport, the sector is generally a low energy intensive user accounting for only 2% of total energy use, the bulk of which is electricity.

Fossil fuel sectors (i.e., coal mining and refineries) account for a smaller share of GVA and employment, 3.3% and 0.7% respectively. Fossil fuel sector employment is concentrated at higher education levels (secondary and tertiary) which make up more than 60% of employment in the sector. Fossil fuel sectors are also very capital intensive (nearly 80% of total outlays). Returns to capital as illustrated in Figure 9 flow largely to higher income households. These sectors, primarily coal mining, however, do account for a significant share of exports, nearly 5%. At the same time, they are also large importers making up 12.7% of total imports.

Energy intensive sectors, here defined as the 20 most energy-intensive users per Rand of output, are key export sectors accounting for nearly 30% of total exports.[1] These sectors are also sizable contributors to total GDP and employment. Energy intensive sectors account for 97% of coal (primarily the electricity sector), 52% of electricity and 72% of liquid fuel use.

Figure 9 shows the sources of household income by representative decile. Low-income households derive the bulk of their incomes from transfers, primarily government, and low skilled labour (Grades 11 and below). Returns to higher educated workers and capital flow disproportionally to higher income households, as does enterprise income.

Table 1: South Africa economic structure (2019)

	Share of total (%)					Intensity (%)	
	GDP (factor cost)	Output	Employment	Exports	Imports	Exports	Imports
Total GDP	100.0	100.0	100.0	100.0	100.0	11.5	14.7
Agriculture	2.3	2.2	5.4	2.4	1.2	12.9	7.4
- Crops	1.4	1.3	3.5	1.9	1.0	17.3	10.6
Mining	9.2	6.5	2.5	34.9	9.2	69.2	12.2
- Coal	2.2	1.3	0.5	4.5	0.0	44.3	0.0
Manufacturing	13.2	23.1	11.2	43.3	73.5	18.1	34.5
- Food	3.5	4.8	2.4	6.6	4.3	11.6	13.9
- Refineries	1.0	1.8	0.3	0.2	5.1	0.8	28.4
- Other	8.6	16.6	8.6	36.4	64.0	21.8	40.2
Other industry	7.2	7.9	9.0	0.8	0.1	1.4	0.2
Services	68.1	60.3	71.8	18.6	15.6	4.1	3.4
Energy intensive	9.3	12.0	5.9	29.2	10.4	26.4	15.3

Notes: For ease of modelling energy imports are included in the SAM as net trade.

Source: Adapted 2019 SAM

[1] The top 20 energy intensive sub-sectors according to the 2019 SAM are in the electricity, transport, refineries, iron and steel, textiles, non-metallic minerals, non-ferrous metals, pulp and paper, mining, chemicals, wood and wood products, agriculture (grape, sugarcane, and forestry) sectors.

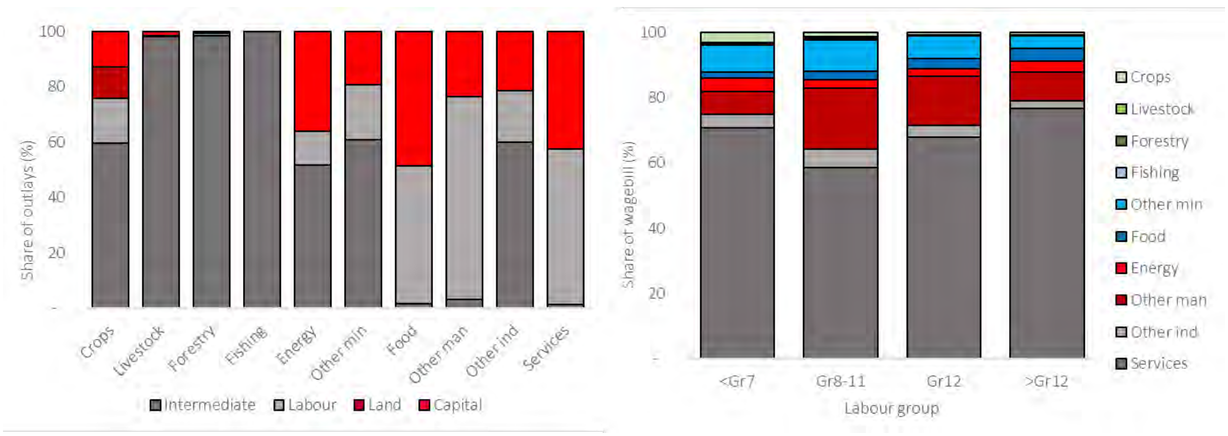


Figure 8: Expenditure by aggregate production sectors, 2019

Source: Adapted 2019 SAM

Clear consumption patterns across household deciles with low-income households disproportionally spending larger shares of their budgets on food (crops and processed foods) than higher income households (see Figure 10). Clear differences exist in household food consumption patterns with low-income households spending a larger share of their food on agriculture products relative to higher income households. Of processed foods, low-income households spend smaller shares of their food budgets on meat and beverages and larger shares on grain, starch, and bakery products relative to higher income households. Energy consumption increases as household income rises with the top four income deciles consuming 70% of total residential energy consumption. The wealthiest decile consumed more than 10 times the energy of the poorest decile. Low-income households' energy sources include coal, electricity, petrol/diesel, kerosene, and LPG while higher income households also consume LPG but no/less coal and kerosene. Table 2 presents household energy consumption volume shares.

Figure 9 Household linkages to production, 2019

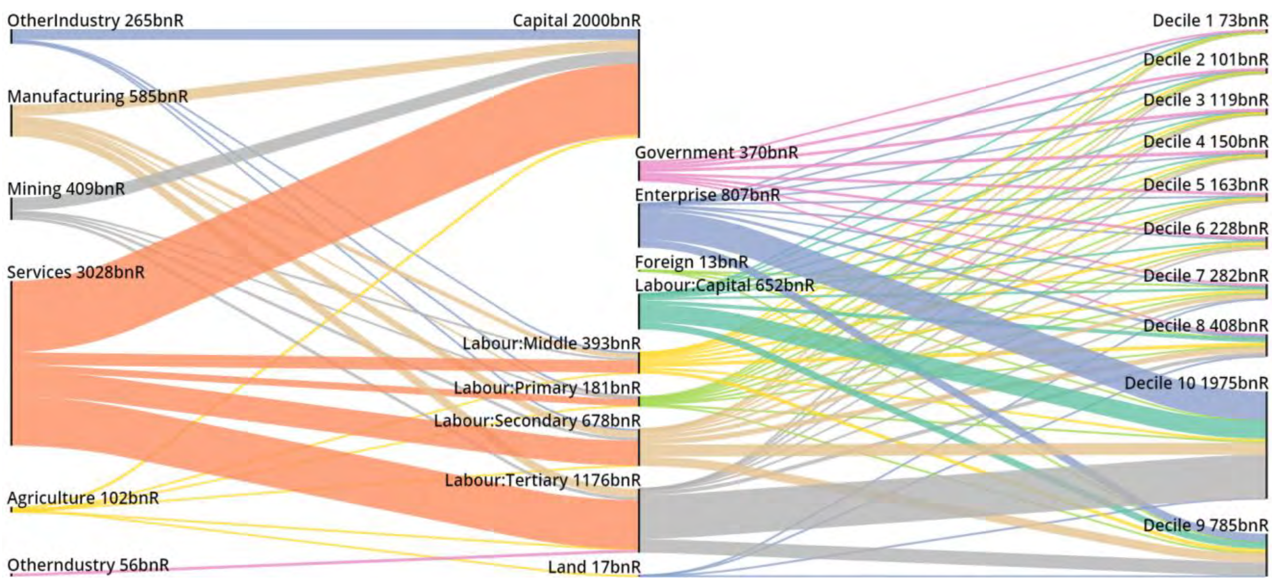


Figure 9: Household linkages to production, 2019

Source: Adapted 2019 SAM

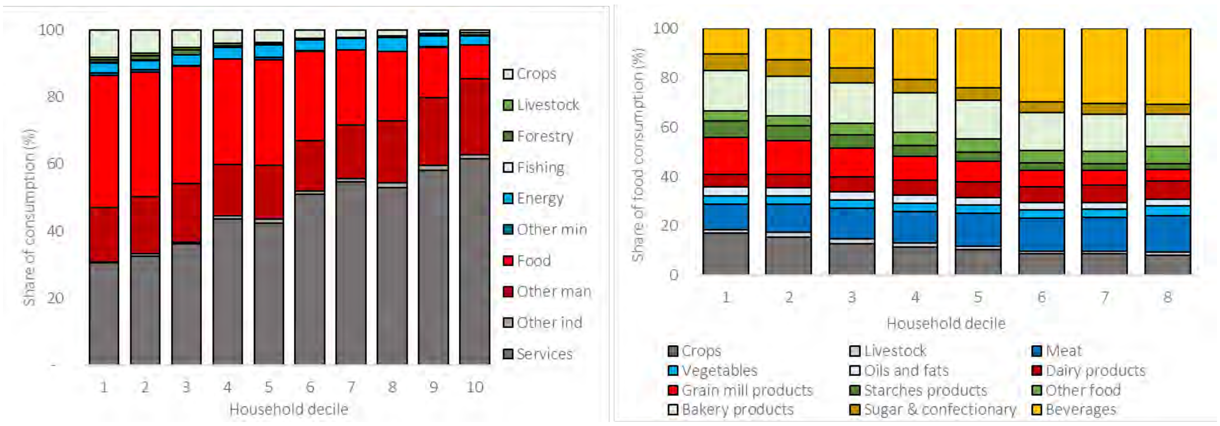


Figure 10: Household consumption expenditure, 2019

Source: Adapted 2019 SAM

Table 2: *Household energy use, 2019*

	Household decile									
	1	2	3	4	5	6	7	8	9	10
Total energy (PJ)	8.1	11.2	13.7	17.7	22.0	26.9	32.5	51.3	60.0	92.8
	Share by fuel									
Coal	15%	16%	6%	4%	11%	14%	9%	2%	1%	1%
Natural gas	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Kerosene	5%	6%	9%	11%	10%	10%	11%	14%	0%	0%
LPG	2%	3%	4%	5%	4%	2%	3%	3%	3%	3%
Electricity	63%	57%	54%	50%	48%	45%	44%	41%	58%	56%
Petrol/Diesel	15%	18%	27%	31%	28%	29%	33%	40%	38%	40%

Source: Adapted 2019 SAM

6. Reference Case

To assess the economic and distributional impacts of climate action a counterfactual or reference case scenario is needed. This scenario presents a potential pathway for energy and economic development with no constraint on emissions. For purposes of this analysis, we take a business-as-usual approach with energy development optimised to meet energy demand in the least cost way. A moderate growth rate of 2.7% is assumed from 2020 to 2050 (see Figure 11). This is in line with the growth projection of the NDC although the short-term forecast has been updated to reflect recent downgrades to the economic outlook by both the South African Reserve Bank (SARB 2023) and the IMF (2023). The data sources informing the baseline growth rate are historical growth, short- to medium-term forecasts from the National Treasury and IMF, and an extrapolation of this going forward with the National Treasury (2019) used as an upper bound for long-term growth. Exogenous assumptions informing growth are kept in line with historical trends and sector total factor productivity is adjusted to reach the targeted growth path. As the analysis takes place over the longer term, we assume an upward sloping labour supply curve. Capital is updated in a dynamic recursive manner in the eSAGE model as such it is dependent on the level of investment made in the previous period. Investment in the eSAGE model is assumed to be a fixed share of absorption which in 2019 was roughly 18%. The government balance can adjust to finance shortfalls in expenditures or save surplus funds. In line with the stylised facts for South Africa, the exchange rate is assumed to be flexible. No mitigation or climate impacts are included in the Reference case.[2]

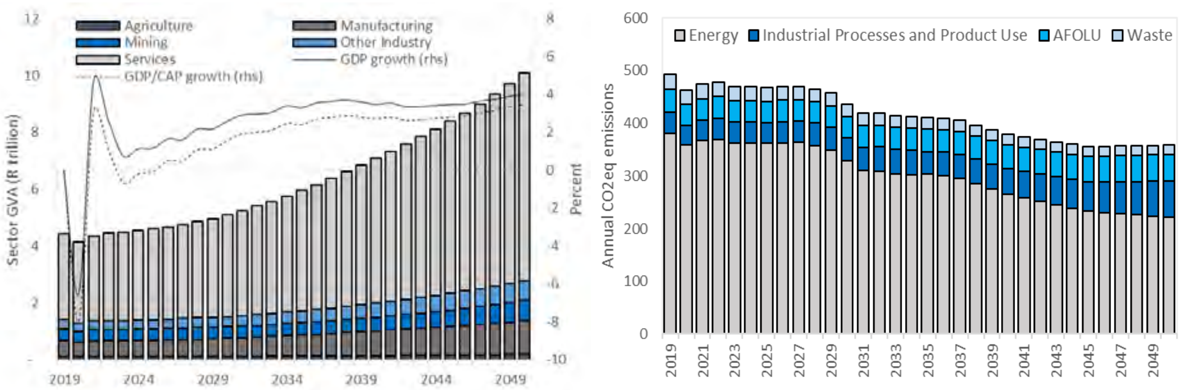


Figure 11: Economic growth projection (left) and Emissions (right)

Source: SATIM-GE Model

Household income and expenditure increases in the Reference case with lower income households experiencing faster average annual growth than higher income households. The rise in income and expenditure is driven by increased employment and higher wages. Primary and middle level educated employment increases by 3% and 2.9% per annum over the period while secondary and tertiary educated employment increases by 2.8% and 2.6%. Household welfare also increases in the Reference case. Real household consumption, which accounts for price and income changes, increases by between 2.9% and 3.4% across household groups with lower income households experiencing larger relative increases than high income households. Relative real consumption changes are higher in lower income households as the change in prices faced by these households, given their consumer baskets, are smaller than in higher income households. Despite shifts in consumption patterns as illustrated in Figure 12, agriculture (i.e. Agriculture) and processed (i.e. Food) foods remain a fairly large share of low-income household consumption baskets and smaller shares of higher income household consumer baskets. Rising low-income consumption results in a decrease in poverty over time with the number of people living below the upper poverty line falling from 28 million in 2019 to 16 million in 2050. The poverty rate decreases from 47% to 20%. The relative shifts in income and consumption in favour of lower income households also results in a decrease in inequality in the Reference case with the Gini index falling from around 60 in 2019 to 58% in 2050.

[2] The underlying assumptions included in the reference case are available on request.

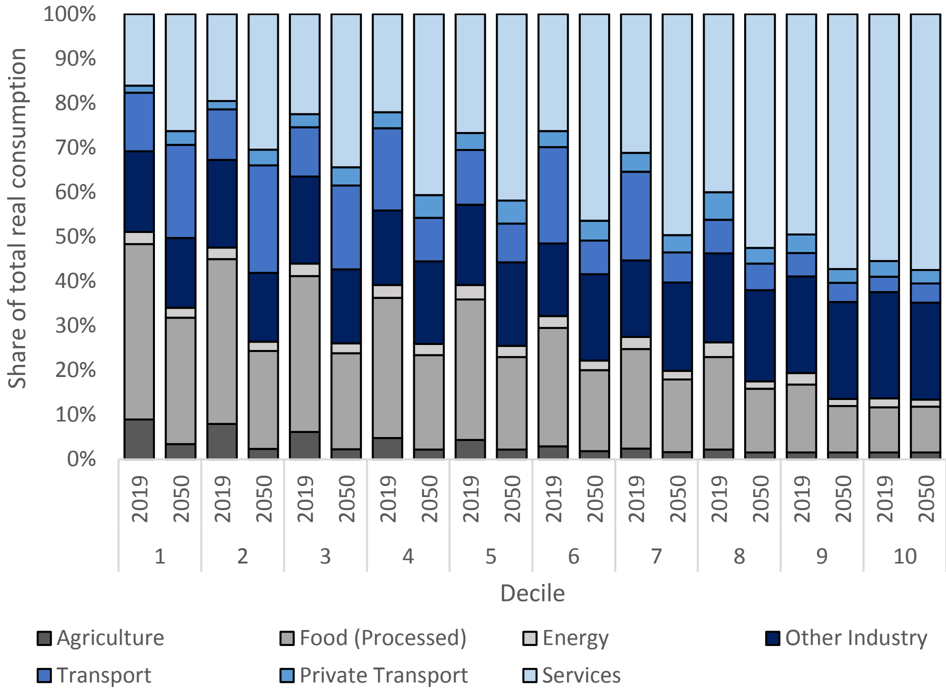


Figure 12: Household consumption commodity shares, 2019 and 2050

Source: SATIM-GE Model

Under the conditions described above, emissions in the Reference case decreases by 27% relative to 2019 primarily due to declines in the energy sector. The use of coal decreases by more than 50% between 2019 and 2050 to account for 33% of total energy use in 2050 relative to 70% in 2019. The decline in coal use is largely due to decreased use in power generation as it is replaced by gas, wind and solar. Wind and solar PV account for 22% of Total Primary Energy Supply (TPES) in 2050 from less than 1% in 2019. Figure 13 presents the change in TPES and power generation in the Reference case. Crude oil use decreases to zero by 2030 as refinery production declines and is replaced with imported liquid fuel sources.

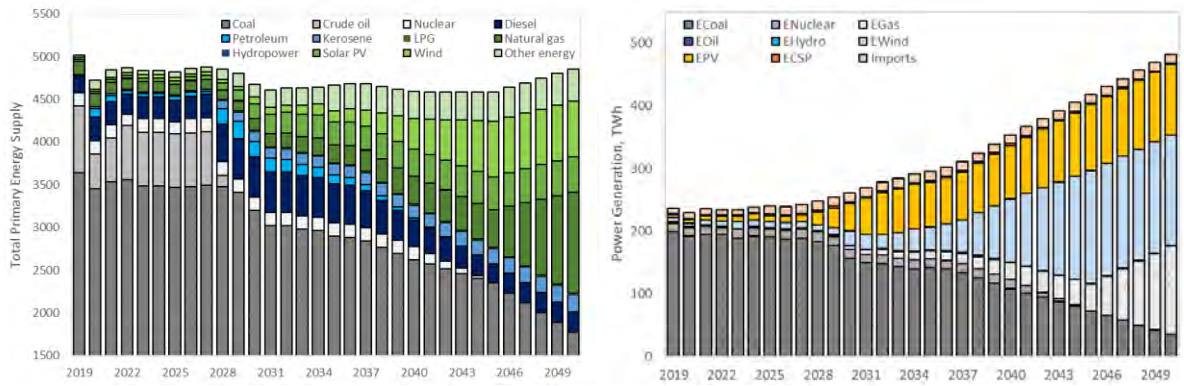


Figure 13: Total Primary Energy Supply (left) and Power generation by technology (right)

Source: SATIM-GE Model

7. Mitigation scenarios

While the Reference case includes a fair amount of mitigation, more ambitious mitigation targets are needed to limit global temperature increases. Two scenarios, i.e., a 9GT and 8GT scenario, are modelled to assess the distributional impacts of more ambitious climate mitigation in South Africa. These scenarios include the upper and lower Updated Nationally Determined Contributions limits by 2030, respectively, as well as a longer-term view of emissions declines by 2050 such that cumulative emissions over the period do not exceed 9GT and 8GT respectively. Cumulative emissions in the Reference case are about 12GT. Larger emissions decreases are thus required under the 8GT than 9GT scenario. Mitigation in the AFOLU and Waste sectors are modelled exogenously and remain relatively consistent between the two scenarios - AFOLU emissions increase from 44 CO_2eq MT in 2019 to 55 in 2050 and Waste emissions decrease from 29 CO_2eq MT in 2019 to 20 in 2050. The balance of emissions reductions come from the Energy and IPPU sectors. All other assumptions are the same as in the Reference case. Figure 14 presents the cumulative emissions for each scenario.

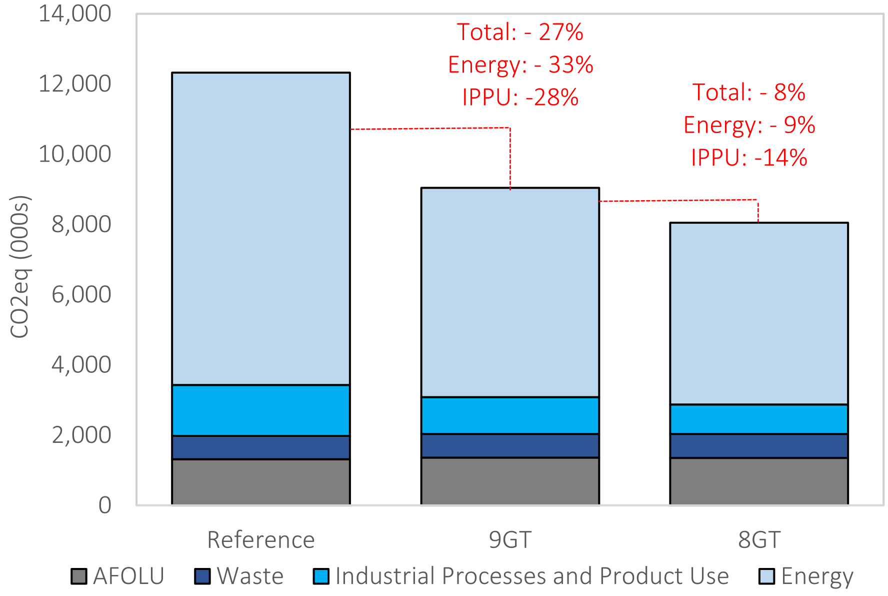


Figure 14: Cumulative emissions per scenario by 2050

Source: SATIM-GE Model

In both scenarios, it is assumed that all the funding needed for mitigation comes from domestic sources. Both the Updated NDC and the JET-IP, however, highlights the need for foreign financing to achieve the necessary mitigation. Funding as discussed above is actively being sought by the South African government to fund the 'just' transition with the IPG already having committed US$8.5 billion. Such funding will assist in reducing the costs of mitigation to the economy and the impact of these costs on households. Two additional scenarios (i.e., 9GTF and 8GTF) are therefore considered whereby all power investment from 2024 is sourced from foreign funding. While it is likely that funds will come from a combination of government, private domestic and international financing, the two scenarios (i.e., purely domestically funded and purely foreign funded) provide a range for the potential impacts of mitigation action in South Africa.

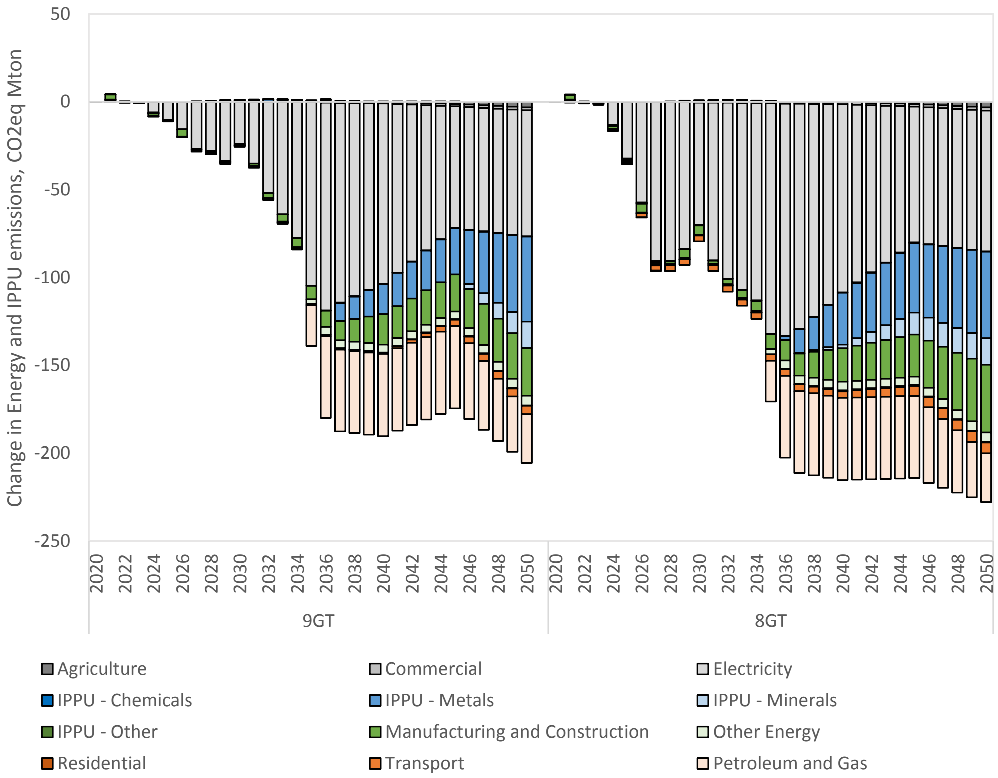
8. Results

8.1. Mitigation and the energy system

Figure 15 (top) presents the annual change in emissions relative to the Reference case in the 9GT and 8GT scenarios. The imposed emissions cap is primarily reached by steep mitigation in the power sector with significant declines in emissions in petroleum, manufacturing and construction, and transport emissions. IPPU emissions in the metals and transport sectors also decrease. Emission declines are driven by a combination of shifts in technology and slower growth. In the power sector (Figure 15 bottom) the decline in emissions is the result of less coal- and gas-based power generation, with the balance being replaced by solar PV and wind. The phase out of coal in power generation is earlier and stronger under the 8GT scenario. By 2050, coal accounts for only 0.4% of power generation in the 9GT and 8GT scenarios relative to 84%

in 2019 and 7% in the Reference case. Solar PV, CSP and wind account for more than 85% (5% in 2019 and 60% in the Reference case).

Decreases in petroleum emissions come from the decline coal-to-liquid (CTL) production as well as the decrease in demand for liquid fuels as the transport sector shifts to cleaner fuels, specifically electricity. In transport, more new light, and heavy commercial vehicles, as well as public transport, are electric. New private transport uses more hybrid vehicles. Manufacturing and construction use of coal for boilers and process heating decreases relative to the reference case. Within the sector, the largest declines are in food, beverages and tobacco, chemicals, and mining.



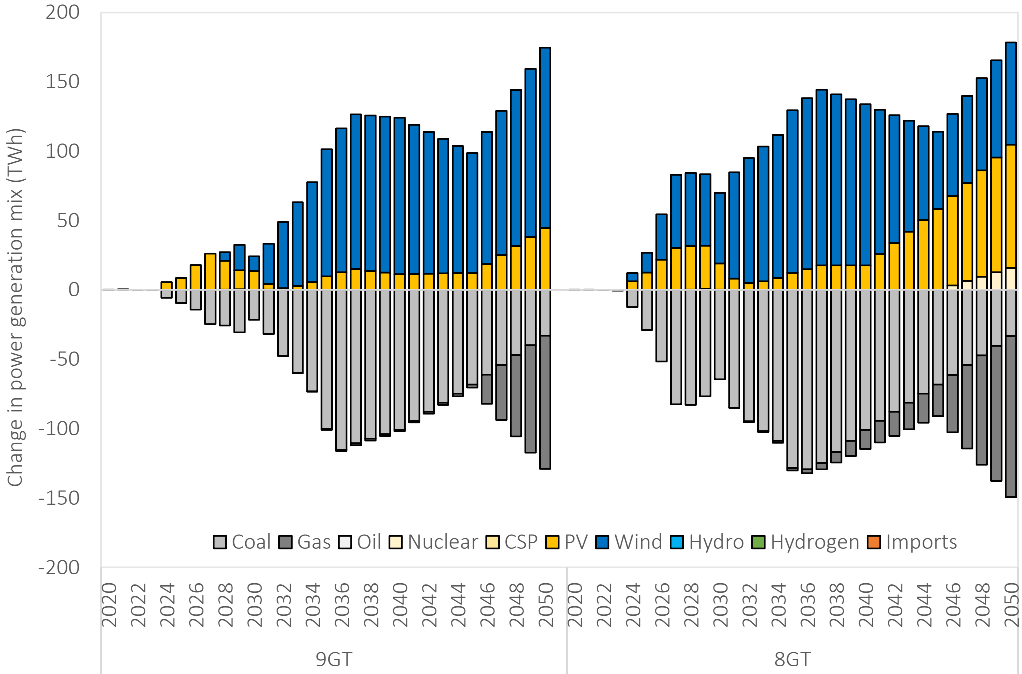


Figure 15: Change in Energy and IPPU emissions (top) and change in power generation by technology (bottom)

Source: SATIM-GE Model

Cumulative power sector investment needed for mitigation under the 9GT and 8GT scenarios is presented in Figure 16 (left), along with the investment needs of the Reference case. By 2049, investment needs are three times larger than that of the Reference case. Cumulative investment between the two mitigation scenarios is similar although more investment is needed in the 8GT scenario particularly in the short term as coal capacity is more quickly replaced by renewable technologies and at larger scale. The rise in investment is associated with an increase in the price of electricity although by 2050 the electricity price is only R0.02 and R0.07 higher per kWh in the 9GT and 8GT scenarios relative to the Reference case. Electricity prices increase faster under the 8GT scenario while prices in the 9GT scenario reflect the Reference case closely up to 2030 whereafter significant price increases are experienced. The decline in electricity prices in the 9 and 8GT scenarios are due to cost savings in power generation as costs of solar, wind and batteries fall.

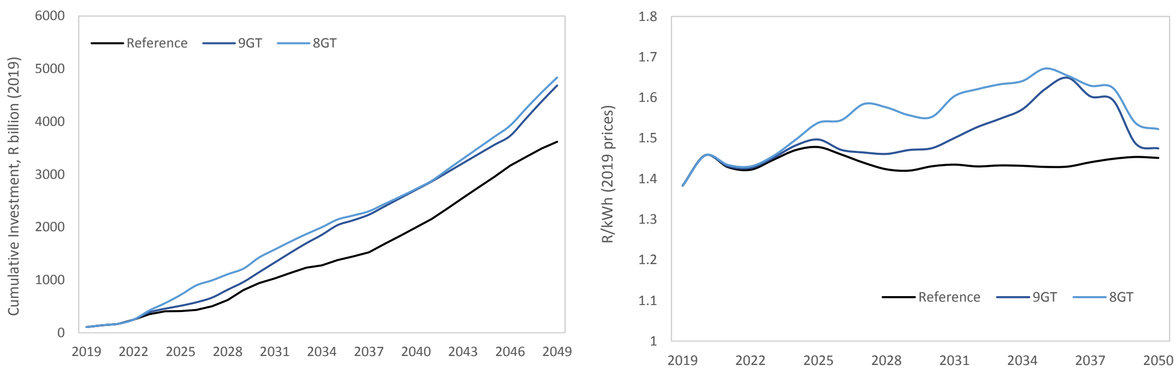


Figure 16: Cumulative power investment (left) and power price (right)

8.2. Economy-wide impacts

Examples of more ambitious mitigation than the near 20% experienced in the Reference case is illustrated by the 9GT and 8GT scenarios. As illustrated in Tables 3 and 4, the level of real GDP and employment is lower in the 9GT and 8GT scenarios relative to the Reference case. By 2050, the level of real GDP is 7.2% and 6.3% lower in the 9GT and 8GT scenarios respectively with more than 2 million fewer jobs being created. By 2050, the average annual real GDP growth rate (from 2019) decreases from 2.7% in the Reference case to 2.2% in the 9GT and 8GT scenarios. Impacts by 2030 are smaller, particularly in the 9GT scenario as the bulk of mitigation in this case takes place post-2030. By 2050, the 8GT scenario has a marginally smaller negative impact on the economy than the 9GT scenario as increased electrification and the development of a larger hydrogen economy (due to technology choices) offsets some of the declines in other sectors and also stimulates activities in other sectors such as services.

GVA losses are broad based as the larger power sector investment requirement crowds out funds for other sectors in the economy, limiting their expansion. We assume in the 9GT and 8GT scenarios that the energy transition is funded locally. Higher electricity prices also increase production costs, resulting in decreased domestic demand.

Coal mining production is more than 50% less in both the 9GT and 8GT scenarios by 2050 due to the decline in domestic demand for coal. By 2030, coal demand in the 9GT and 8GT scenarios is 5% and 19% lower than in the Reference case, respectively - primarily due to lower demand from the power sector. By 2050, coal demand is 60% and 70% lower, with lower power demand accounting for less than a third of the decline, and waning demand from refinery and industry making up the remaining difference. By 2050, petroleum refinery production ceases due to lower demand which is met by imports. Outside of coal mining and refinery, the sector production most affected by mitigation is other manufacturing and services. Within other manufacturing the chemicals and non-ferrous metals sector are the largest affected. Declines in chemicals are linked to decreases in refinery production – Sasol, a key petroleum producer in South Africa, accounts for about 50% of chemicals production in South Africa. The drop in production relative to the Reference case is similar across service sub-sectors, although relatively smaller differences are seen in transport.

Table 3: Change in level of real GVA relative to the Reference case

Percent change in level of GVA relative to Reference case				
	2030		2050	
	9GT	8GT	9GT	8GT
Total GDP	-0.73	-2.47	-7.19	-6.32
Agriculture	-0.75	-1.98	-3.54	-5.72
Crops	*-0.58*	*-1.48*	*-0.78*	*-3.00*
Mining	-1.60	-5.52	-5.89	-7.43
Coal	*-4.72*	*-19.09*	*-57.74*	*-67.38*
Manufacturing	-0.81	-2.39	-9.10	-8.12
Food	*-0.86*	*-2.24*	*-4.15*	*-6.78*
Refinery	*11.04*	*11.04*	*-100.00*	*-100.00*

Other	*-1.05*	*-2.76*	*-10.38*	*-8.02*
Other industry	-0.25	-1.33	-2.37	9.89
Services	-0.66	-2.27	-7.57	-7.48

Source: SATIM-GE Model

Economy-wide declines in production result in lower employment in most sectors across the economy. Employment differences are largest in the services, other industry and other manufacturing sectors as these sectors employ the largest number of workers per unit of output after the agriculture sector. Employment in the coal mining and refinery sector decreases in line with the declines in production. By 2050 between 19,000 and 24,000 fewer workers are employed in the coal mining sector, 5,100 jobs are lost in petroleum refining. New job opportunities are also created in the hydrogen economy, electricity sector and within some agriculture sub-sectors. These gains are however insufficient to offset the wider loss in jobs.

Table 4: Change in level of employment (thousands) relative to the Reference case

Change in level of employment relative to Reference case (thousands)				
	2030		2050	
	9GT	8GT	9GT	8GT
Total GDP	-92.8	-353.3	-2,308.5	-2,468.4
Agriculture	-6.2	-15.4	-19.3	-76.2
Crops	*-4.4*	*-10.3*	*4.4*	*-30.7*
Mining	-3.6	-12.4	22.4	-17.2
Coal	*-2.3*	*-9.8*	*-19.6*	*-24.3*
Manufacturing	-21.0	-55.3	-347.0	-367.1
Food	*-3.2*	*-7.8*	*-23.3*	*-42.6*
Refinery	*0.9*	*0.9*	*-5.1*	*-5.1*
Other	*-18.8*	*-48.4*	*-318.7*	*-319.5*
Other industry	-2.0	-20.5	-349.1	-233.0
Services	-60.0	-249.7	-1,615.4	-1,774.8

Source: SATIM-GE Model

The lower levels of employment in the 9GT and 8GT scenarios is across labour skill categories although the largest differences relative to the Reference case is for the middle and secondary educated labour. Primary skilled jobs experience the smallest difference. Changes in employment by skill align to sector changes in employment as the other manufacturing and services sectors employ relatively larger shares of middle and secondary educated workers, and other industry sector employs a larger share middle educated labour.

Table 5: Change in employment by education group

Change in level of employment relative to Reference case (thousands)				
	2030		2050	
	9GT	8GT	9GT	8GT
Primary	*-12.5*	*-52.8*	*-403.3*	*-388.2*
Middle	*-36.9*	*-135.0*	*-807.8*	*-874.8*
Secondary	-28.3	-105.1	-666.4	*-777.0*
Tertiary	-15.1	-60.4	-431.0	-428.4

Source: SATIM-GE Model

8.3. Household distributional impacts

By 2050, household income and consumption expenditure are lower relative to the Reference case under both the 9GT and 8GT scenarios. Declines in income and expenditure are larger in higher income households. Declines in real household expenditure is smaller than real incomes as changes in prices are also accounted for. Higher income households primarily receive their incomes from labour, capital, and enterprise income which decrease under mitigation due to both lower returns as well as employment. Lower income households receive the bulk of their incomes from transfers and lower skilled employment which experience smaller decreases in employment.

Table 6: Change in household income (left) and consumption expenditure (right) by representative group

Percentage difference in real household income relative to Reference case					
		2030		2050	
		9GT	8GT	9GT	8GT
Decile	1	-0.34	-1.60	-5.87	-5.66
	2	-0.36	-1.66	-6.03	-5.82
	3	-0.39	-1.75	-6.21	-6.05
	4	-0.42	-1.83	-6.45	-6.26
	5	-0.46	-1.94	-6.74	-6.52
	6	-0.51	-2.06	-7.15	-6.83
	7	-0.56	-2.21	-7.56	-7.24
	8	-0.60	-2.30	-7.85	-7.43
	9	-0.62	-2.38	-8.16	-7.55
	10	-0.63	-2.42	-8.22	-7.57
Total		-0.58	-2.26	-7.74	-7.24

Percentage difference in real household expenditure relative to Reference case					
		2030		2050	
		9GT	8GT	9GT	8GT
Decile	1	-0.20	-1.07	-4.78	-3.77
	2	-0.22	-1.14	-4.94	-3.93
	3	-0.25	-1.23	-5.14	-4.17
	4	-0.28	-1.32	-5.38	-4.40
	5	-0.32	-1.43	-5.70	-4.68
	6	-0.38	-1.58	-6.14	-5.02
	7	-0.43	-1.74	-6.60	-5.46
	8	-0.48	-1.86	-6.96	-5.71
	9	-0.52	-2.01	-7.43	-5.96
	10	-0.54	-2.10	-7.58	-6.02
Total		-0.45	-1.81	-6.79	-5.48

Source: SATIM-GE Model

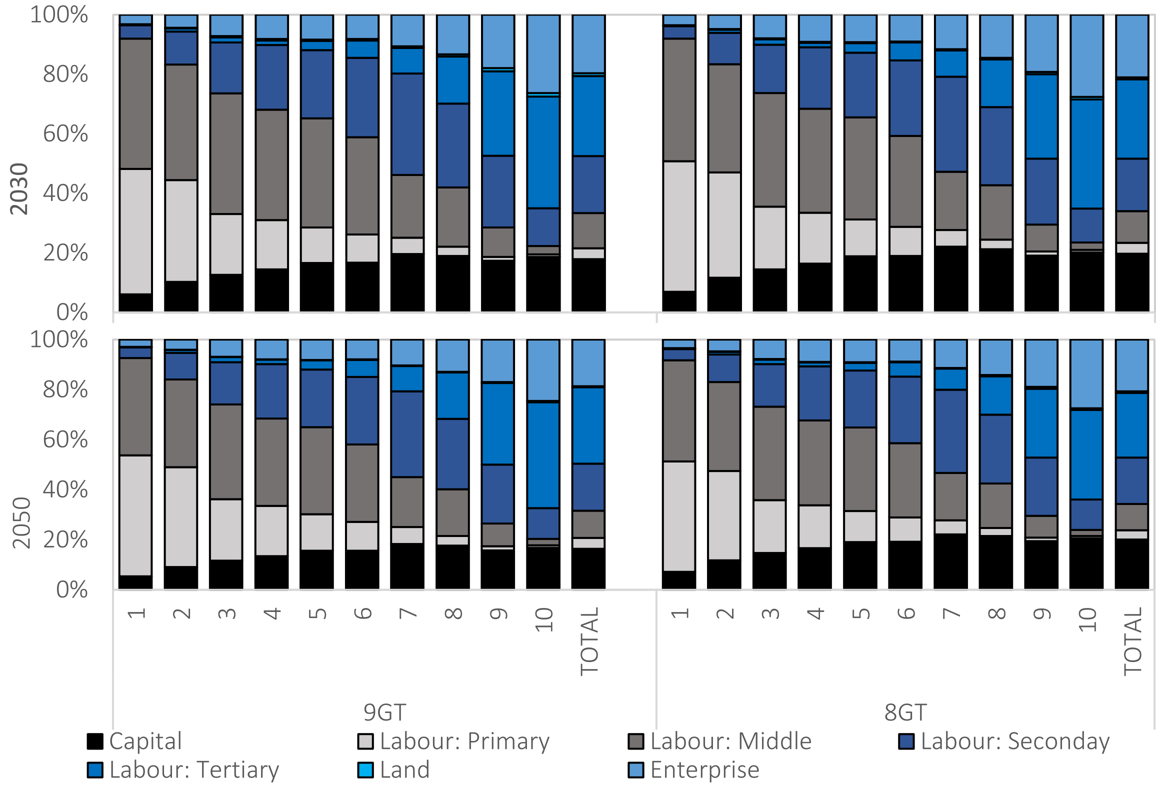


Figure 17: Contribution to change in income by source

Source: SATIM-GE Model

Declines in household consumption expenditure are concentrated in services as illustrated in Figure 18 which shows the percentage point contribution of consumed goods and services to the overall change in household consumption expenditure. Household deciles are grouped into low-, middle- and high-income households for ease of reading. Consumption levels are lower than in the Reference case across all households although more so in high income households than low-income households, reflecting the differences seen in income as well. Consumption shares of both agriculture and processed foods increase across households, although the level of food consumption is lower than in the Reference case.

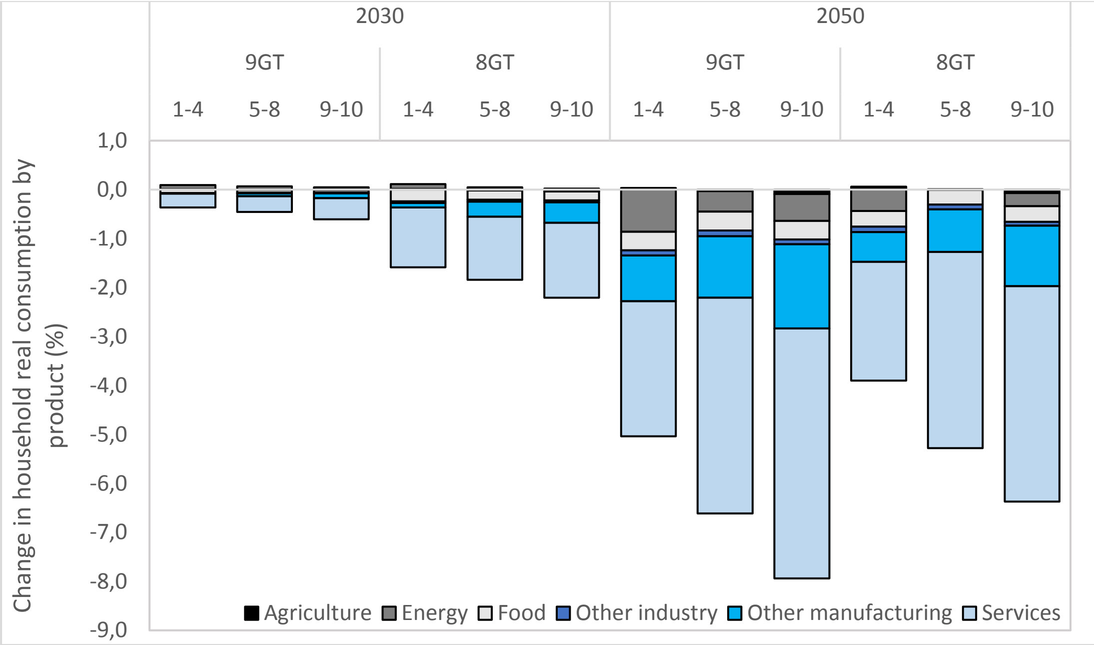


Figure 18: Change in real household consumption expenditure by commodity

Source: SATIM-GE Model

8.4. Implications for poverty and inequality

Poverty levels are higher under the 9GT and 8GT scenarios. By 2050, the number of people living below the upper poverty line increases by just over 1 million relative to the Reference case. In terms of the headcount poverty rate, this translates into 1.6 and 1.4 percentage points. Poverty increases more under the 8GT scenario by 2030 than the 9GT scenario as more mitigation takes place at a faster rate and earlier requiring more investment. By 2050, however, poverty under the 9GT scenario is higher. The number of people living below poverty also increases using the lower and food poverty lines, although these increases are smaller. Both the poverty gap and severity of poverty increases by 2050. Inequality changes are small relative to the Reference case.

Table 7: Change in poverty metrics

		Change relative to Reference case					
		Headcount poverty rate (%-points)			Number of people living below		
Poverty line		Food	Lower	Upper	Food	Lower	Upper
9GT	2030	0.05	0.14	0.15	35,330	94,853	103,290
	2050	0.47	0.84	1.65	364,146	649,286	1,273,981
8GT	2030	0.30	0.59	0.67	199,041	395,871	445,559
	2050	0.29	0.64	1.36	227,916	493,093	1,050,883

		Change relative to Reference case					
		Poverty gap index			Poverty gap index squared		
Poverty line		Food	Lower	Upper	Food	Lower	Upper
9GT	2030	0.03	0.05	0.07	0.01	0.03	0.05
	2050	0.13	0.30	0.66	0.05	0.14	0.35
8GT	2030	0.14	0.24	0.35	0.07	0.13	0.23

2050	0.10	0.23	0.52	0.04	0.11	0.27

Source: SATIM-GE Model

9. Global climate financing

Table 8 presents the impact of mitigation under the 9GT and 8GT scenarios relative to the Reference case counterfactual with international climate funding available for power sector investments. As illustrated, mitigation with climate financing reduces the cost of mitigation in the economy making the structural transition to cleaner energy smoother. In the 9GT scenario, climate mitigation financing results in a higher level of real GDP relative to the Reference case. In the 8GT scenario, the level of real GDP is still lower than in the Reference case, but the scale of the difference is much smaller at less than 1%. There are however still structural changes in the economy when pursuing more ambitious mitigation targets. This can be seen in the lower sector GDP for the mining and manufacturing sectors – these negatives are driven by declines in coal mining, and petroleum refining and chemicals production. The electricity sector, and other industry, experience an increase in GDP relative to the Reference case as the economy becomes more electrified. Services and agriculture experience higher levels of real GDP.

A larger number of jobs are created under mitigation scenarios with climate financing. The creation and loss of jobs are aligned to sector GDP impacts with new opportunities created in other industry, services and agriculture and jobs losses in sectors such as coal mining and petroleum and chemical manufacturing. On aggregate the rise in employment results in lower poverty levels than in the Reference case - poverty decreases when considering all poverty lines, including food poverty. Income and expenditure differences between the climate financing mitigation scenarios and Reference case is more favourable to lower income households, although changes in inequality are small.

Table 8: Impacts of global climate financing (select key indicators)

	9GT		8GT	
	2030	2050	2030	2050
% difference in level from Reference case				
Total GDP	0.7	0.6	-0.4	-0.6
Agriculture	-0.5	1.8	-1.6	0.9
Mining	-1.4	-2.7	-2.6	-3.8
Manufacturing	-4.0	-5.3	-8.2	-6.2
Other industry	2.1	5.3	1.6	3.7
Services	1.5	1.3	0.7	0.0
level difference from Reference case (thousands)				
Total Employment	289	597	166	129
Agriculture	-7	44	-16	33
Mining	-35	-93	-62	-129
Manufacturing	-16	-18	-27	-21
Other industry	154	270	176	168
Services	193	395	94	78
Poverty headcount - level difference from Reference case (thousands)				
Upper Poverty Line	-1611	-1417	-1596	-1100

Lower Poverty Line	-1908	-961	-1839	-784
Food Poverty Line	-1123	-581	-1073	-443
Inequality - difference from Reference case				
Gini index	-0.0001	0.0007	-0.0004	0.0001
Palma ratio	0.0005	0.0156	-0.0108	-0.0024

Source: SATIM-GE Model

10. The cost of inaction

To contextualise the costs of more ambitious mitigation in South Africa, this paper also considers the cost of inaction, specifically through trade. While 193 countries across the world have set initial mitigation targets through their NDCs (151 provided updates to commitments at the 27th annual Conference of the Parties (COP) in Egypt), mitigation ambition across the global landscape is not equal. As of March 2022, only 60 of 195 countries have committed to reaching net zero emissions, with 27 of these being in the European Union (EU). To discourage carbon leakage and protect domestic production, countries with more ambitious mitigation targets may impose trade restrictions to account for the carbon content of imported goods. An example of such an action is the EU carbon border adjustment mechanism (CBAM) which was formally approved by the European Parliament in April 2022. The EU CBAM is a tariff placed on the emissions content of goods imported into the EU. The tariff which is to be informed by the EU Emissions Trading Scheme (ETS) price, will be gradually phased in from 2026 and will initially only be imposed on select commodities (namely cement, iron and steel, aluminium, fertiliser, electricity, and hydrogen) with additional requirements being phased in over time as the EU ETS is phased out. Other countries such as the US, Canada and Japan are also considering the implementation of carbon border adjustment measures.

To assess the implications of such action and cost the impact of inaction by South Africa, we consider two additional scenarios. The first (EUCBAM) considers the impact of the EU CBAM as described above. A CBAM is placed on the carbon content of South African cement, iron and steel, aluminium, fertiliser, electricity, and hydrogen exports. The CBAM is set to €85 per tonne of carbon dioxide equivalent emissions and is phased in over 4 years.[3] The second scenario (GlobalCBAM) considers the same CBAM as in EUCBAM with the exception that the CBAM is applied to the carbon content of all exports. All assumptions in the EUCBAM and GlobalCBAM scenarios are the same as in the Reference.

Key impacts of inaction as described above are presented in Table 9. CBAM is found to have a negative impact on economic development and household welfare with real GDP and employment decreasing relative to the Reference case; and poverty and inequality increasing. The impacts are more negative under the GlobalCBAM than EUCBAM as more of SA's exports are subjected to the CBAM affecting more of the production sectors in the economy. The level of real GDP is 9.3% lower by 2050 in the GlobalCBAM scenario, this is larger than the estimated losses of 6.3% and 7.2% for the ambitious 8GT and 9GT mitigation scenarios. Higher

[3] The €85 per tonne used in these scenarios was the ETS price on the 5 May 2023 (see https://ember-climate.org/data/data-tools/carbon-price-viewer/). The ETS price changes daily, both increasing and decreasing depending on supply and demand of emissions for trading and has historically breach the €100 mark.

CBAM prices than considered here, which have already occurred in the EU ETS market, would have a larger negative impact on the economy and household welfare.

Table 9: Impacts of CBAM (select key indicators)

	EUCBAM		GlobalCBAM	
	2030	2050	2030	2050
% difference in level from Reference case				
Total GDP	-0.3	-0.9	-1.8	-9.3
Agriculture	0.9	-0.6	0.4	-3.3
Mining	0.8	2.9	-1.4	-17.3
Manufacturing	0.3	-1.4	0.7	-4.8
Other industry	-1.7	-1.5	-3.8	-8.7
Services	-0.4	-1.2	-2.1	-9.5
level difference from Reference case (thousands)				
Total Employment	-61	-351	-581	-3999
Agriculture	23	-8	7	-81
Mining	15	55	-12	-213
Manufacturing	6	-56	9	-260
Other industry	-43	-63	-232	-811
Services	-61	-280	-353	-2635
% difference from Reference case				
Total Exports	0.0	0.1	0.6	-10.1
Agriculture	3.6	-0.4	-0.9	-1.7
Mining	2.7	6.6	-0.5	-22.1
Manufacturing	-3.8	-6.1	6.0	4.7
Other industry	-55.6	-16.8	-55.0	-16.2
Services	2.0	-1.3	-1.6	-10.0
Poverty headcount - level difference from Reference case (thousands)				
Upper Poverty Line	218	288	1481	2741
Lower Poverty Line	176	96	1313	1613
Food Poverty Line	159	54	725	905
Inequality - difference from Reference case				
Gini index	0.0005	0.0001	0.0001	0.0004
Palma ratio	0.0150	0.0085	0.0014	0.0203

11. Discussion and future work

This analysis provides a preliminary assessment of the impacts of ambitious climate mitigation actions in South Africa and their distributive effects on the economy including the impacts on poverty and inequality. The Reference case highlights a decrease in emissions in the country when following a least cost energy plan. Renewable energy technologies are cheaper relative to traditional fossil fuels and replace ageing coal capacity. Previous studies have shown that under such conditions there is no longer a trade-off between mitigation and economic development (Arndt et al. 2020).

The mitigation scenarios analysed here, i.e., the 9 and 8GT emission constraints, force faster decarbonization of the economy and require more investment in cleaner technologies. This slows economic activity and employment creation and relative to the Reference case both real GDP and employment are smaller. The loss in real GVA ranges between 6% and 7%, as a result the level of real GDP in the 9GT and 8GT scenarios lag that of the Reference case by between 4 and 5 years.

Relative to the Reference case, household income and expenditures are negatively affected by the more ambitious levels of mitigation. This has the effect of increasing the number of people living below the poverty line (upper, lower and food) and increases the severity of poverty despite higher income households being more negatively affected than lower income households. This result highlights the need for complementary supportive measures to protect vulnerable households.

Climate financing, as illustrated in Section 9 can however offset some or all the costs related to increased mitigation ambition and lead to an outcome where poverty declines are experienced despite ambitious mitigation reductions. Structural changes still occur in the economy as electricity production shift toward cleaner technologies and lower levels of sector GDP are still seen for some sectors. These are however offset by gains or smaller declines in other sectors.

The results from the boarder tax adjustment scenarios highlight that no action carries significant potential costs to the economy as well. We consider the impact of boarder tax adjustments on select, and all exported goods and services in the Reference case. When all exports all considered, a border tax adjustment has a larger negative impact on the economy by 2050 than 9GT or 8GT scenarios with no climate financing. Poverty and inequality also rise under such action.

As with any analysis and modelling tools there are limitations, this study is no exception although it does put forward a useful modelling framework for comparing the costs associated with different policies and can be used to explore complementary policies for offsetting the impacts of mitigation.

Some key exclusions in the analysis that requires further investigation include:

- Opportunities related to the global shift toward cleaner energy: The global shift to cleaner energy creates economic opportunities for South Africa including in the supply of critical minerals such as platinum (IEA 2023). These are not directly modelled as appropriate strategies and policies must be put in place for South Africa to become a key player.
- External benefits associated with lower mitigation: Co-benefits from cleaner energy such as reduced health costs and increased labour productivity are also not accounted for. Naidoo et al. (2019) provide some estimates of the health benefits associated with the shift to cleaner power generation.
- Constraints in the flow and availability of needed resources: The CGE model assumes the efficient relocation of resources such that economic growth is maximised. The transition may not unfold in this manner and resources may be earmarked for certain sectors. Similarly, we also assume, although not in an unconstrained manner, that the necessary resources for changes in the economy are available. This again may not transpire and if these skills are imported, the impacts from such labour would be different to that assumed here for domestic workers.

In terms of future model developments, a key improvement to the modelling framework would be to include the transition of household income sources over time (e.g., shifts in labour income due to rising education levels) as well as a more sophisticated microsimulation module. Regional differences are excluded in this analysis as the CGE model is at the national level. While the microsimulation module links households from different regions to the national representative households in the CGE model, a regional CGE model would better capture the impacts of climate mitigation action in specific regions such as the coal mining sector, which is concentrated in the Limpopo and Mpumalanga province, and link these to households within these regions in the microsimulation module. This is currently not possible in the current framework and regional inequality and poverty impacts calculated would be underestimated for some regions and overestimated in others.

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Appendices

Appendix A:

2019 Social Accounting Matrix Accounts

Sectors	Sectors	Commodities	Commodities	Other
Agriculture:Wheat	Paper	Agriculture:Wheat	Petroleum - Diesel	Labour - Grade 7 and lower
Agriculture:Maize	Printing	Agriculture:Maize	Petroleum - Petrol	Labour - Grade 8-11
Agriculture:Other cereals	Petroleum products	Agriculture:Other cereals	Petroleum - LPG	Labour - Grade 12
Agriculture:Vegetables	Hydrogen	Agriculture:Vegetables	Petroleum - Kerosene	Labour - Higher than Grade 12
Agriculture:Other fruit	Ammonia	Agriculture:Other fruit	Petroleum - HFO	Capital - Energy
Agriculture:Grapes	Basic chemicals	Agriculture:Grapes	Hydrogen	Capital - Other
Agriculture:Oil seeds	Other chemicals	Agriculture:Oil seeds	Ammonia	Households: Decile 1
Agriculture:Tubers	Rubber	Agriculture:Tubers	Basic chemicals	Households: Decile 2
Agriculture:Pulses	Plastic products	Agriculture:Pulses	Other chemicals	Households: Decile 3
Agriculture:Sugarcane	Non-metallic minerals	Agriculture:Sugarcane	Rubber	Households: Decile 4
Agriculture:Other crops	Iron and steel	Agriculture:Other crops	Plastic products	Households: Decile 5
Agriculture: Live animals	Non-ferrous metals	Agriculture: Live animals	Non-metallic minerals	Households: Decile 6
Forestry	Metal products	Forestry	Iron and steel	Households: Decile 7
Fishing	Machinery	Fishing	Non-ferrous metals	Households: Decile 8
Mining: coal	Fuel cells	Mining: high-grade coal	Metal products	Households: Decile 9
Mining: gold	Electrolysers	Mining: low-grade coal	Machinery	Households: Decile 10
Mining: natural gas	Electrical machinery	Mining: natural gas	Fuel cells	Domestic transaction costs
Mining: platinum	Scientific equipment	Mining: platinum	Electrolysers	Export transaction costs
Mining: metal ores	Vehicles	Mining: metal ores	Electrical machinery	Import transaction costs
Mining: other mining	Other transport equipment	Mining: other mining	Scientific equipment	Enterprises
Processed: Meat	Furniture	Processed: Meat	Vehicles	Activity taxes
Processed: Fish	Other manufacturing	Processed: Fish	Other transport equipment	Direct taxes
Processed: Vegetables	Electricity	Processed: Vegetables	Furniture	Import tariffs
Processed: Oils and fats	Natural water	Processed: Oils and fats	Other manufacturing	Sales taxes
Processed: Dairy products	Construction	Processed: Dairy products	Electricity	Energy price differentials
Processed: Grain mill products	Trade services	Processed: Grain mill products	Natural water	Government
Processed: Starches products	Hotels and accommodation	Processed: Starches products	Construction	Savings and investment
Processed: Animal feed	Land transport - freight	Processed: Animal feed	Trade services	Changes in stocks
Processed: Bakery products	Land transport - passenger	Processed: Bakery products	Hotels and accommodation	Rest of world
Processed: Sugar	Other transport - freight	Processed: Sugar	Land transport - freight	
Processed: Confectionary products	Other transport - passenger	Processed: Confectionary products	Land transport - passenger	
Processed: Pasta products	Private transport	Processed: Pasta products	Other transport - freight	
Processed: Food n.e.c.	Supporting transport services	Processed: Food n.e.c.	Other transport - passenger	
Processed: Beverages and tobacco	Communication	Processed: Beverages and tobacco	Private transport	
Textiles	Financial services	Textiles	Supporting transport services	
Clothing	Business services	Clothing	Communications	
Leather products	Government services	Leather products	Financial services	
Footwear	Other services	Footwear	Business services	
Wood products		Wood products	Government services	
		Paper	Other services n.e.c.	
		Printing	Imported energy goods	

Appendix B:

Microsimulation module

The approach, while simple, provides improved measurement of inequality and poverty metrics as it includes a finer resolution of households as opposed to the representative households provided in the eSAGE. The use of the microsimulation module also enables an analysis of inequality and poverty metrics for different household characteristics (e.g., spatial location, race, and gender) which is not included in the CGE model.

In the standard TD-MA, information on household income and prices are applied to the household survey data. This influences expenditure which is used to measure changes in welfare. The changes are generally passed on as percent deviations from baseline as the survey and national accounts data are often not aligned in level terms. In building the SAM only the shares of expenditure and income from the household survey is used.

Pauw and Thurlow (2011) uses the TD-MA approach in RIAPA for the assessment of poverty in Tanzania. Instead of passing income and commodity price changes from the CGE model to the survey data, the authors pass along information on household expenditure changes by commodity. By doing so, behavioural adjustments from the CGE model are accounted for in the microsimulation group for households corresponding to representative households in the CGE model. This is an improvement to the standard TD-MA approach which otherwise would include no behavioural change.

The microsimulation module used in the TSITICA project follows the approach of Pauw and Thurlow (2011). The argument for doing so is that eSAGE includes behavioural change for households based on their income changes over time. Specifically, household consumption patterns begin to resemble those of the neighbouring representative household groups as their incomes increase. This important as it accounts for changes in the consumer price baskets faced by different household groups and the impact of policies on these baskets. For example, households in the 10th percentile of the income distribution (decile 1) may not consume a lot of electricity and may instead consume other fuels such as wood or paraffin to meet energy needs. As incomes in these households increase, an increase in the use of electricity may rise as these households are now able to afford electrical appliances. Changes in electricity prices thus now become a feature of their consumer baskets where they were not before. Mitigation actions affect the price of electricity as it often requires the build of new low/no mitigation technologies for power generation. Not accounting for the change in consumer preferences for electricity would miss the impact of changing electricity prices on the welfare of these households.

As an expenditure approach is taken in the microsimulation module, metrics for inequality and poverty are calculated based on expenditure per capita. This opens the potential measure of inequality and poverty at different levels of consumption including food and energy.

A key assumption informing these metrics would be the change in population and number of households. The CGE model does not directly use population as an input to its solution. Population (by household representative group) is used to calculate per capita metrics for welfare analysis. As a first pass at improved inequality and poverty assessment in the linked energy-economic modelling framework, and to keep the model input assumption simplistic, we assume that changes in population are uniform across households and as a result do not impact the inequality metric. While this assumption does have implications for poverty analysis (for example if higher population growth is experienced in low-income households relative to wealthier households, the poverty incidence rate may be underestimated), the uncertainty of changes in population growth by income group lends it to be a fair assumption. Future research could consider different specifications.

Future work to enhance the CGE model and microsimulation module included in the TSITICA project could include but are not limited to the estimation of an education transition matrix to inform labour supply growth assumptions, shifting household labour income source shares in relation to the education matrix, adjustment of other income shares, including changes in household characteristics, accounting for non-uniform changes in population, inclusion of new households with different incomes which may change the household mapping to deciles, and accounting for migration.

Linking income with behavioural changes with regards to employment status: in this case the microsimulation module would include information on changes in incomes, commodity prices and consumption shares from the CGE model.

The figure below illustrates how the microsimulation module works.