ESRG

ENERGY SYSTEMS RESEARCH GROUP
University of Cape Town

Technical Analysis to support the update of South Africa's First NDC's mitigation target ranges

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Glossary

AFOLU – Agriculture, Forestry and Other Land Use

AR5 – The IPCC's Fifth Assessment Report

CAT – Climate Action Tracker

CCGT – Closed-Cycle Gas Turbine

CER – Centre for Environmental Rights

CERC – Climate Equity Reference Calculator

CERF – Climate Equity Reference Framework

CGE – Computable General Equilibrium economic model

CSP – Concentrated Solar Power

DAFF – Department of Agriculture, Forestry and Fisheries (now the Department of Agriculture, Land Reform and Rural Development)

DFFE – Department of Fisheries, Forestry and the Environment

DMRE – Department of Mineral Resources and Energy

EAF – Energy Availability Factor

ESAGE – Energy – South African General Equilibrium Model

GDP – Gross Domestic Product

GHG – Greenhouse Gas(es)

GTS – Green Transport Strategy

GVA – Gross Value Added

GWP – Global warming Potential

IEA – International Energy Agency

IMF – International Monetary Fund

IPCC – Intergovernmental Panel on Climate Change

IRENA – International Renewable Energy Agency

IRP – Integrated Resource Plan

MTSAO – Medium Term System Adequacy Outlook

NDC – Nationally Determined Contribution

NIR – National Inventory Report

NPC – National Planning Commission

NWMS – National Waste Management Strategy

OCGT – Open-Cycle Gas Turbine

PA – Paris Agreement

PV – solar Photo Voltaic panels

RE – Renewable Energy

REIPPPP – Renewable Independent Power Producer Programme

SAR – The IPCC's Second Assessment Report

SARB – South African Reserve Bank

SATIM – South African TIMES model

SATIMGE – SA TIMES – ESAGE linked energy-economy-environment model

TIMES – The Integrated MARKAL-EFOM1 System – an energy modelling platform maintained by IEA-ETSAP

UNFCCC – United Nations Framework Convention on Climate Change

WEO – The IEA’s World Energy Outlook

Executive Summary

This technical analysis was undertaken to support the Department of Fisheries, Forestry and Environment in updating South Africa's 2015/16 NDC target ranges. It forms a companion piece of analysis with a report on South Africa's legal obligations under the Paris Agreement regarding NDCs, and on South Africa's "fair share" of the global mitigation challenge.

The analysis aims to establish where South Africa's GHG emissions will be in 2025 and 2030, given the twin uncertainties of economic growth and policy implementation. The challenge of projecting economic growth over the next decade was compounded by the occurrence of the COVID pandemic. Two growth rates were used – a reference growth rate which reaches a value of 2.4% by 2030, and a high growth rate which reaches a value of over 4% by 2030. An ultra-high growth rate was added for sensitivity purposes of 5.4% from 2021. These are presented, along with the Treasury's short-term forecast from October 2020, in Figure 1 below.

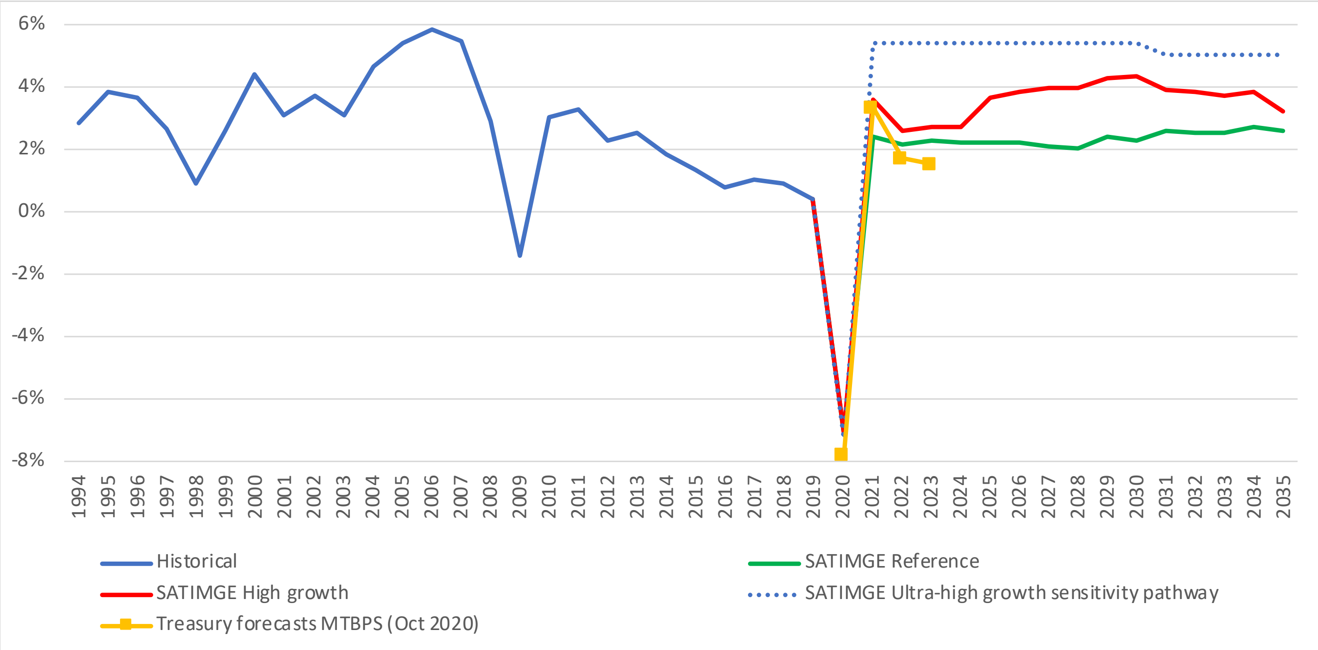

Figure 1 - Historical and projected GVA growth rates, along with Treasury's short-term forecast.

The uncertainty associated with policy implementation was addressed by modelling two scenarios:

1. An Existing policies scenario, which included policies, measures and programmes currently being implemented, including the National Waste Management Strategy, the committed capacity in the IRP 2019, and also the retirement of Eskom's coal plants as planned in the IRP.
2. A Planned policies scenario, which in addition to the above, includes the following:
    a. The new capacity in IRP 2019, with slight adjustments for delays in procuring new capacity;
    b. The Green Transport Strategy, modelled conservatively;
    c. The draft post-2015 National Energy Efficiency Strategy;
    d. The Carbon Tax;
    e. The biofuels strategy.

Both scenarios were modelled with both growth rates, using the SATIMGE modelling framework developed by the Energy Systems Research Group at the University of Cape Town. SATIMGE consists of two hard-linked models – the South African TIMES model, a technology-rich energy/economy/environment model built on the energy modelling platform TIMES, and the Energy-South African General Equilibrium Model of the South African economy, with further disaggregation of the energy sector – and waste and AFOLU sector models, which together are able to model all GHG emissions sources in the South African economy.

Sensitivities were also run on the oil price, on the Energy Availability Factor of Eskom's coal fleet, on an ultra-high growth rate, with different degrees of policy implementation, and with scaled-back versions of the IRP. A careful comparison was also undertaken between the 2017 draft National GHG Inventory and the modelling framework.

The results of the analysis are presented in Figure 2 below. The green bars represent a range of emissions outcomes for the reference growth rate, from no implementation (the Existing policies scenario) to full implementation (the Planned policies scenario). The implementation of the IRP 2019 on its own, with no other mitigation policies, would still result in significant savings. The grey bars to the top and bottom of the green bars represent an uncertainty margin in estimation of GHGs, to account for improvements in the national inventory, and/or data errors in the modelling framework. The red bars represent the same range with the high growth rate. The grey bars represent the same range with the ultra-high growth rate. The "likely emissions range" combines the two.

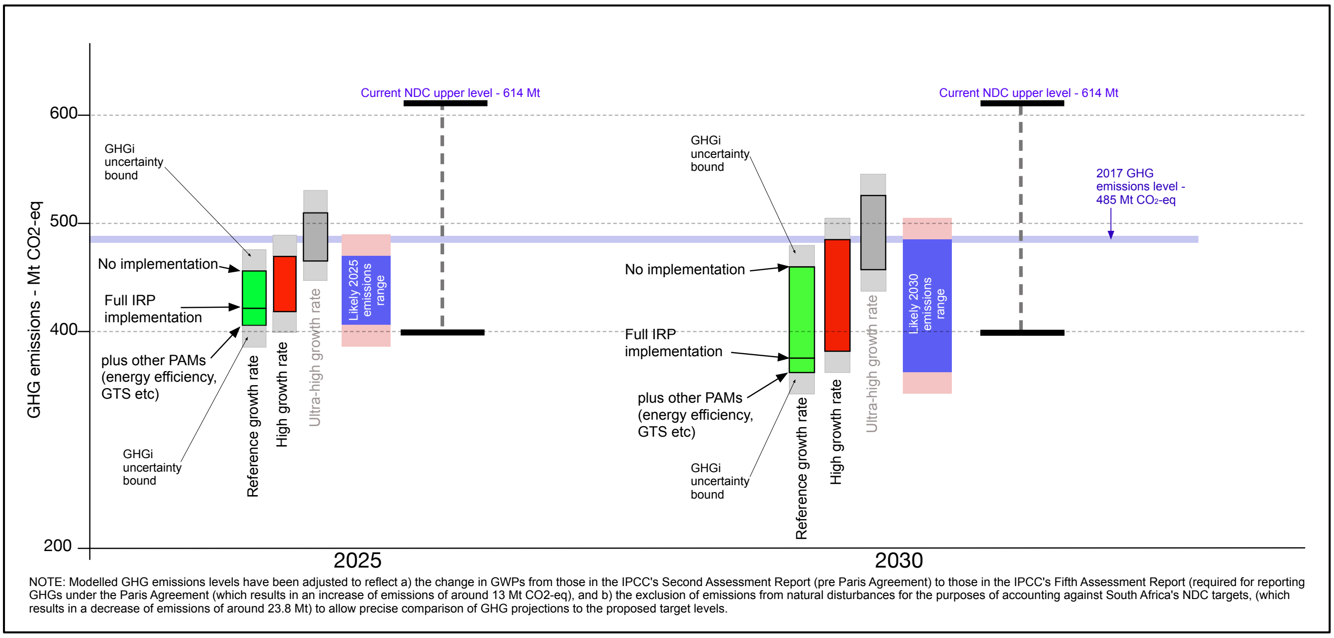

Figure 2 - Range of likely GHG emissions outcomes for the South African economy in 2025 and 2030, given uncertainties in policy implementation, economic growth rates and GHG estimation.

The implication of this analysis is that South Africa can considerably reduce its NDC target upper ranges for 2025 and 2030. In 2030, consideration should be, given to the reduction of the lower end of the target range as well. The updated "fair share" analysis for 2030 indicates that South Africa's target range should be extended to be fully consistent with one or both of the Paris Agreement's temperature thresholds.

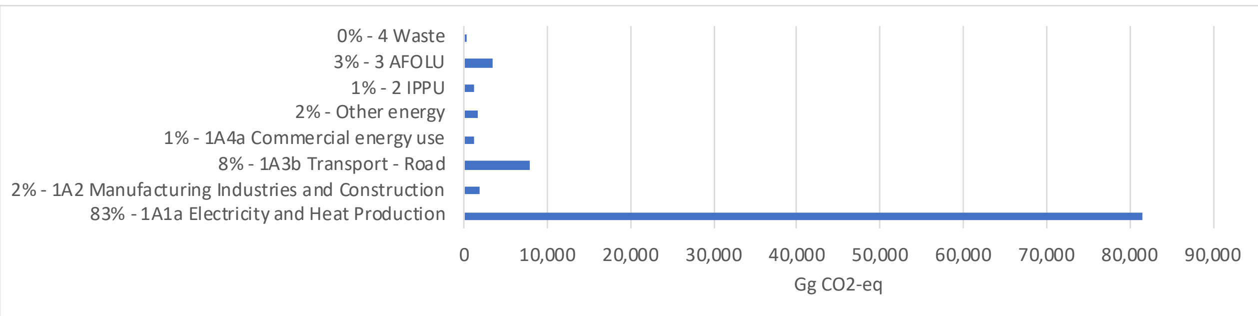

Figure 3 -Mitigation by IPCC sector / category in 2030 (Existing policies scenario minus Planned policies scenario, using the reference growth rate)

The key driver for mitigation is the electricity sector, as presented in Figure 3 above, which constitutes 83% of the overall mitigation which results from the full implementation of the policies and measures above. The second largest contributor, at 8%, is a reduction in emissions from road transport, as a result of a combination of passenger and freight modal shifts and technology change accelerated by the Green Transport Strategy. It should be noted that the reduction in emissions in the electricity sector is partly driven by a much lower demand forecast than assumed in the IRP 2019. Since the same investment plan is assumed, the additional capacity (mainly renewable energy) displaces more coal power than anticipated in the IRP, which leads to substantially lower emissions. This also however results in higher electricity prices, which are exacerbated by energy efficiency measures implemented in the context of a fixed investment plan, which in turn has a negative impact on economic growth. A slightly scaled-back renewable energy plan, without the more expensive coal and hydroelectricity in the IRP, mitigates most of this effect. While this study did not explore this question further, there is therefore scope to do further work on a) the potential for a more economically-optimal electricity plan, revised in the light of the economic impact of the COVID pandemic, with the same mitigation outcome, which also meets socioeconomic goals, and b) the potential for further mitigation by 2030 linked to international support.

1 Introduction

This technical report has been undertaken to support the Department of the Environment, Fisheries and Forestry in their updating of South Africa's first Nationally Determined Contribution (NDC) under the Paris Agreement. It provides the evidence base for deciding on updated mitigation targets for South Africa for 2025 and 2030. It should be read jointly with a companion piece of analysis on South Africa's legal obligations under the Paris Agreement and South Africa's "fair share" contribution to achieving the temperature goal of the Paris Agreement. The analysis considers likely GHG emissions pathways for South Africa to 2030 with and without the implementation of currently planned policies and measures, including the IRP 2019, the Green Transport Strategy, the post-2015 National Energy Efficiency Strategy and the Carbon Tax, as well as policies and measures currently being implemented, including the National Waste Management Strategy. The likely GHG outcome of these is assessed against two economic growth rates. The analysis does NOT consider the possibility of implementing additional mitigation policies and measures. The report concludes with recommendations on new target ranges for the updated NDC.

2 South Africa's anticipated emissions levels in 2025 and 2030

The goal of this analysis is to determine a range of likely GHG emissions outcomes in 2025 and 2030, taking into account key uncertainties, in order to map the relationship between policy implementation and GHG emissions. The three key factors which will determine the range of GHG emissions outcomes in 2025 and 2030 are South Africa's base year GHG emissions levels (here, the year 2017), economic growth, and the degree to which currently planned policies and measures with significant mitigation impacts are implemented.

The starting point of the analysis is to draw a distinction between a broader analysis which considers mitigation actions which are technically possible in the 2020s, and a more narrow analysis which considers only mitigation actions what are contained in current policies, in terms of South Africa's current national circumstances. It is therefore important to emphasise that this is NOT a mitigation potential analysis, and that the GHG emissions trajectories presented below do not preclude the possibility of more ambitious mitigation pathways for the 2020s resulting from mitigation actions currently NOT contained in current policies. In addition, the compatibility with GHG emissions pathways which would achieve the long-term goal of net zero emissions by 2050, as referenced in South Africa's Low Emissions Development Strategy communicated to the UNFCCC in 2020, has not been assessed here[1]. The planned policies and measures which have been assessed here are listed below.

GHG emissions outcomes have been estimated using an integrated GHG emissions modelling framework described below. An extensive comparison between base year emissions in the modelling framework and those in the latest National Inventory Report was carried out. One of the key drivers for GHG emissions is economic growth, and therefore two economic growth rates have been modelled – a "reference" growth rate, based on existing economic growth trends, and a high economic growth rate, based on the successful implementation of a range of growth-oriented economic policies during the 2020s. In addition, sensitivity analyses to a number of key factors were also modelled, as described below. A detailed account of results per sector is also provided below.

2.1 Methodology

2.1.1 Overview

The methodology used in this analysis is based on the use of an energy-economic environment modelling framework – SATIMGE – consisting of dynamically-linked TIMES energy model used to model energy and industrial process emissions (SATIM), a CGE model to model the economy (ESAGE), and linked spreadsheet-based models to model the AFOLU and waste sectors. The modelling framework is calibrated with base year energy, emissions and other activity data from the DMRE's energy balances, the National Inventory Report, and other sources. Key drivers are GDP growth and population, which are described in detail below.

[1] Net zero CO_2 emissions pathways for South Africa are being modelled in the second phase of this project, expected to conclude by the end of June 2021.

2.1.2 Basic drivers – Population and Economic Growth

2.1.2.1 Population

Population projections are taken from Stats SA (StatsSA 2020a) and table A.1 in the United Nations Department of Economic and Social Affairs "World Population Prospects 2019", vol. 1 (United Nations Department of Economic and Social Affairs 2019). Over the key modelling period the national population grows from 59 million (2020) to 66 million (2030). Assumptions concerning the total population are constant for all scenarios. The population is divided into three income groups with fixed thresholds which drive household energy demand. The number of people in each income group changes over time with economic growth. The population trajectory in each income group, with a reference economic growth rate, as well as total population, is presented in Figure 4 below.

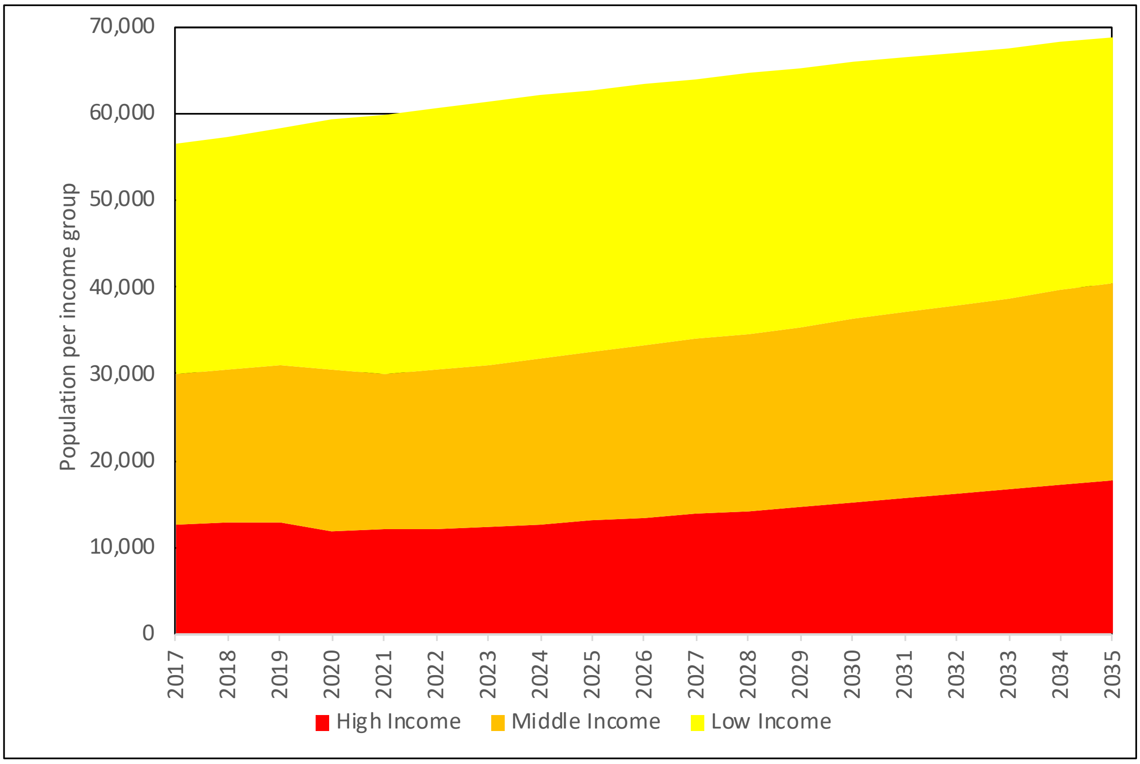

Figure 4 - Population and division into major income groups, 2017-2035

2.1.2.2 Economic growth

Economic growth is one of the key drivers of GHG emissions, and therefore assumptions regarding future economic growth levels are key drivers for modelling future GHG emissions. The key challenge in the current circumstances (the COVID-19 pandemic) is both assessing the economic impact of the COVID-19 lockdown in 2020 and the years immediately after, and assessing the growth path South Africa will take over the next decade, in the light of the economic impact of COVID. For the current analysis, there is a significant risk of underestimating GHG emissions for 2025 and 2030, as a result of underestimation of the GDP growth rate. In order to mitigate this risk, two growth rates have been modelled, and a sensitivity analysis has been undertaken on a very high (but very unlikely) growth rate.

In February 2020, before the COVID-19 pandemic, economic growth was expected to be sluggish over the next 5 years (2020-25) due to cyclical and structural factors facing South Africa. This contrasts with expectations of a decade earlier expressed in the National Development Plan of growth rates of over 5% annually. As can be seen from Figure 5 below, GDP growth has been below 4% over the last decade, and declined to very low levels by 2019.

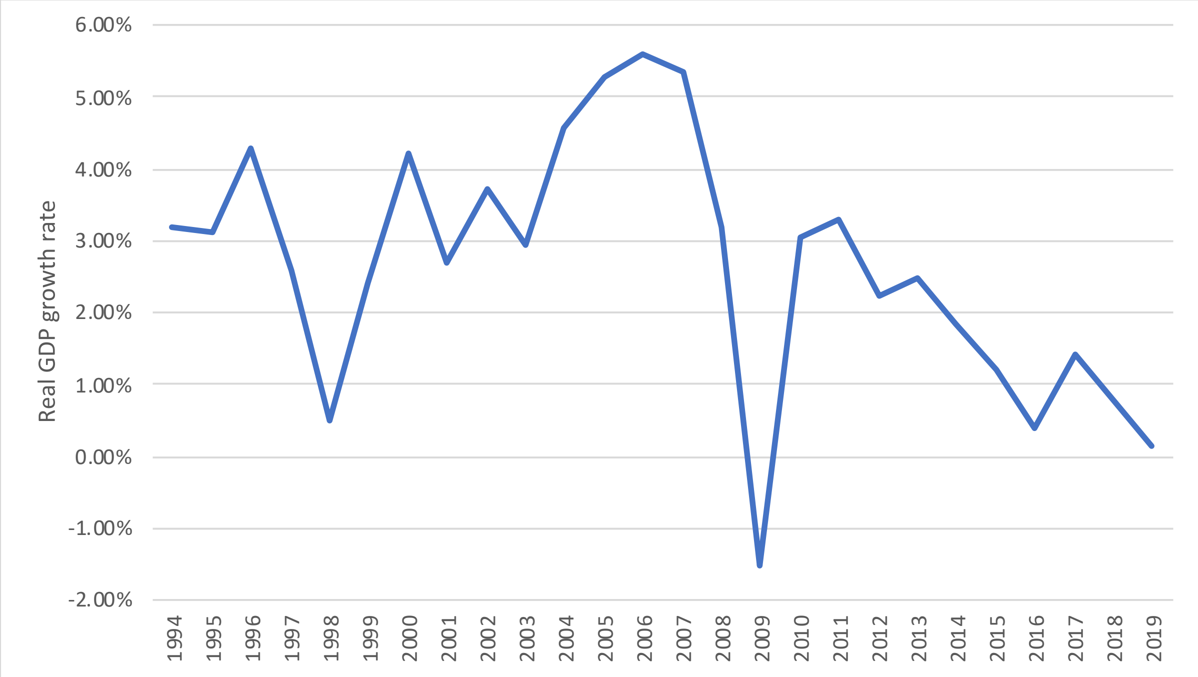

Figure 5 - Real GDP growth rate, 1994-2019

The 2020 National Treasury Budget (before COVID) forecasted growth of 0.9% for 2020 rising to 1.6% in 2022, with a potential growth rate of between 1% and 1.5% estimated for the short to medium term (National Treasury 2020a). The IMF forecasted growth to reach only 1.8% by 2024 (International Monetary Fund 2020a). Table 1 shows the very low levels of GDP growth that were expected for South Africa by various national and international agencies before the COVID pandemic.

Table 1: Pre-COVID economic forecasts for South African GDP growth

	Date of forecast	2020	2021	2022	2023	2024
Moody's	February 2020	0.7%	0.9%			
SARB	March 2020	-0.2%	1.0%	1.6%		
IMF	October 2019	1.1%	1.4%	1.8%	1.8%	1.8%
National Treasury	February 2020	0.9%	1.3%	1.6%		

By April 2020 all major credit rating agencies had downgraded South Africa's sovereign credit status to non-investment ("junk") status, as the COVID crisis was unfolding, further complicating economic recovery, and raising the cost of government borrowing to address the crisis. This was also exacerbated by a rapidly-deteriorating ZAR-USD exchange rate.

The COVID-19 pandemic has resulted in the need to revise these expectations, particularly for 2020, due to the shutdown of much economic activity in South Africa in March and April (during the Level 5 lockdown) and the slow re-opening of the economy from May. The global pandemic has also affected global trade and financing, as governments prioritise spending on essential services. Similarly in South Africa, the pandemic has resulted in the need for additional government spending to support frontline services for combating the pandemic, the domestic economy and the many households negatively affected by the impacts of the lockdown. Projections made after the COVID pandemic had begun for economic growth in 2020 for South Africa were between -7% and -8%, although larger declines of -12% have also been estimated (National Treasury 2020b) (Bureau For Economic Research 2020) (South African Reserve Bank 2020) (Arndt et al. 2020). These forecasts are presented in Table 2 below.

Table 2 - Post-COVID economic forecasts for South African GDP growth

	2020	2021	2022	2023
National Treasury GDP growth forecasts from the Medium Term Budget Policy Statement in October 2020	-7.8%	3.3%	1.7%	1.5%
Bureau for Economic Research, Stellenbosch University, April 2020	-9.5%	3.1%	1.4%	1.5%
OECD Economic Outlook, September 2020	-11.5%	1.4%	-	-
South African Reserve Bank Monetary Policy Committee, November 2020	-8.0%	3.5%	-	-
International Monetary Fund, World Economic Outlook, October 2020	-8.0%	3.0%	-	-

The depth of the 2020 recession will have a significant impact on the size of the economy in the 2020s, and therefore GHG emissions. The nature of the COVID crisis will also have a more complex effect on GHG emissions than recessions usually do (for instance the 2008 recession), since in many instances the response to the lockdown has been uneven across the economy. For instance, although StatsSA reports that the GDP had declined in the second quarter of 2020 by 17% compared to the second quarter of 2019 (StatsSA 2020b), electricity consumption declined at a smaller rate – electricity demand in the second quarter of 2020 was 13.8% lower than in the second quarter of 2019, and close to 2019 levels by August 2020 (StatsSA 2020c).

Similarly, the impact and timing of the rebound on growth is uncertain, as this depends on not only the pace of the recovery in South Africa, which in itself is uncertain, but also on the pace of recovery globally, given the dependency of the South African economy on exports and on international tourism. Assumptions about the speed and timing of the rebound, combined with the depth of the 2020 recession, have an impact on economic growth assumptions for both 2020 and 2021, and a very significant impact on the assumed size of the GDP going forward. Estimated growth rates for 2021 range between 1.4% and 3.5% (National Treasury 2020b) (Bureau For Economic Research 2020) (South African Reserve Bank 2020) (International Monetary Fund 2020b)(Arndt et al. 2020). These might be overoptimistic given the current developments worldwide. Most countries including South Africa faced additional COVID infection waves, and new strains of the virus have emerged and are emerged, including in South Africa. On the other hand, vaccines are being successfully deployed, but will take 8 to 16 months to be deployed at scale everywhere.

The COVID pandemic will also have an impact on medium to long term growth projections. While weak fundamentals prevail, additional borrowing to support the economy and people of South Africa during COVID results in a significant decline in fiscal space, which prior to the pandemic was already under pressure. The tighter fiscal environment not only affects the government's ability to spend and invest in the economy going forward, but also could result in future tax increases and negatively affects business confidence. Whilst the risks to the medium to long term growth outlook are larger to the downward side, quick and efficient implementation of appropriate government reforms could assist in boosting economic growth. The impact of this slowed growth on the size of the South African economy is very significant, and will impact GHG emissions significantly, particularly via an impact on electricity demand. Figure 6 below presents the resulting size of the South African economy (GDP) which would result from these GDP growth projections. The GDP growth projection on which basis electricity demand was projected for IRP 2019 is included in the figure, and averages 4.5% in the period from 2019 to 2025 (CSIR 2017) (Government of South Africa 2019). Most projections foresee the economy only reaching 2019 levels in 2024, whereas the pre-COVID more optimistic projections underlying electricity demand in IRP 2019 see the economy as having grown to 1.4 times its 2019 size by 2025. The short-term impact on electricity demand of the COVID crisis is not straightforward and will be discussed in relation to modelling of the electricity sector.

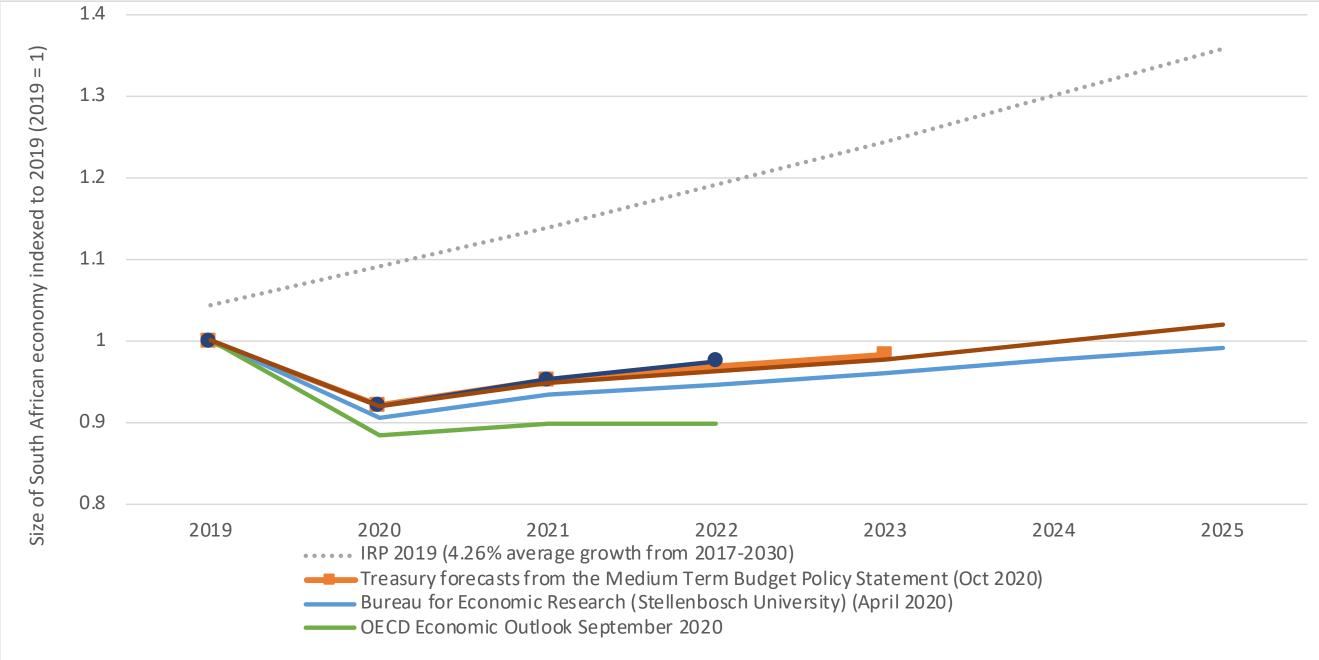

Figure 6 - Post-COVID size of the South African economy resulting from post-COVID GDP growth projections, relative to 2019 GDP

The most recent formal development plan for South Africa is the National Development Plan (NPC 2011) which outlined several reforms to help the country reach an average growth rate of over 5% for the period 2010 to 2030. To date this vision has not materialised, with real growth averaging 1.7% between 2010 and 2019 (StatsSA 2020b). The impacts of COVID and weak economic fundamentals further highlight the low probability of South Africa achieving such growth rates over the next decade. In 2013, the South African Reserve Bank (SARB) released a policy paper (Faulkner, Makrelov, and Loewald 2013) that also discussed key structural changes needed to the economy to set the country on a higher growth path. Addressing the constraints identified in this paper was estimated to increase potential growth by 2.7 percentage points. The National Treasury (National Treasury 2019) has presented a more recent analysis of the potential for growth in South Africa going forward. In its paper “Economic transformation, inclusive growth, and competitiveness: A contribution towards a growth agenda for the South African economy”, the National Treasury highlights that successful implementation of the various reforms identified could increase economic growth by 2.3 percentage points (from the potential growth rate of 1.5%) over a 10-year period. To a large extent National Treasury (2019) and SARB (2013) consider similar constraints to economic growth in South Africa with perhaps a key distinction in constraints being the inclusion of mark-up reductions which is included in the ‘Higher competition levels’ scenario from SARB (2013).

Given the uncertainties related to the outlook for South Africa both in the short and medium term two scenarios are considered in this analysis. The first is an optimistic ‘Reference’ growth trajectory based on the current conditions facing South Africa, which also aligns in the short term to the forecasts of the National Treasury (2020 Supplementary Budget) and the SARB (May 2020). In the ‘Reference’ case growth is therefore expected to rebound from Q3 as lockdown measures are relaxed, although economic growth remains weak. Real GDP is only expected to reach 2019 levels at the start of 2024. Weak domestic fundamentals, the constrained fiscal space, electricity supply constraints and low global growth will cause growth to remain weak and below the pre-COVID trajectory.

The second scenario is a high growth trajectory for the country which considers the potential to successfully unlock key constraints to the economy, as identified by the National Treasury and SARB in their respective papers above. This scenario is primarily based on National Treasury (2019) but also accounts for the impact of higher competition levels from SARB (2013) which are not fully accounted for in National Treasury (2019). This is included by taking half the projected impact and adding it to the impact of the Treasury reforms. Half of the ‘Higher competition levels’ scenario impact is considered for several reasons - these include differences in timing of the modelling which influences the base year - mark-ups in South Africa have decreased since SARB

(2013) lowering the potential impact on the economy; the partial capturing of these reforms in National Treasury (2019); and the fact that the sum of the impact of individual reforms is not the same as the combined impact of reforms, as other structural limitations may be reached under the latter. Both SARB (2013) and National Treasury (2019) included significant modelling efforts which lie outside the scope of this project. For this reason, three key channels (i.e. total factor productivity, foreign investment and labour supply growth) are used to achieve similar expansions in the economy as identified in the above-mentioned papers, maintaining the sector development trends reported. This 'High growth' scenario is included to account for any upside risks to economic growth. In addition to the reforms an upper-end recovery for 2021 is also assumed, namely 3.6%.

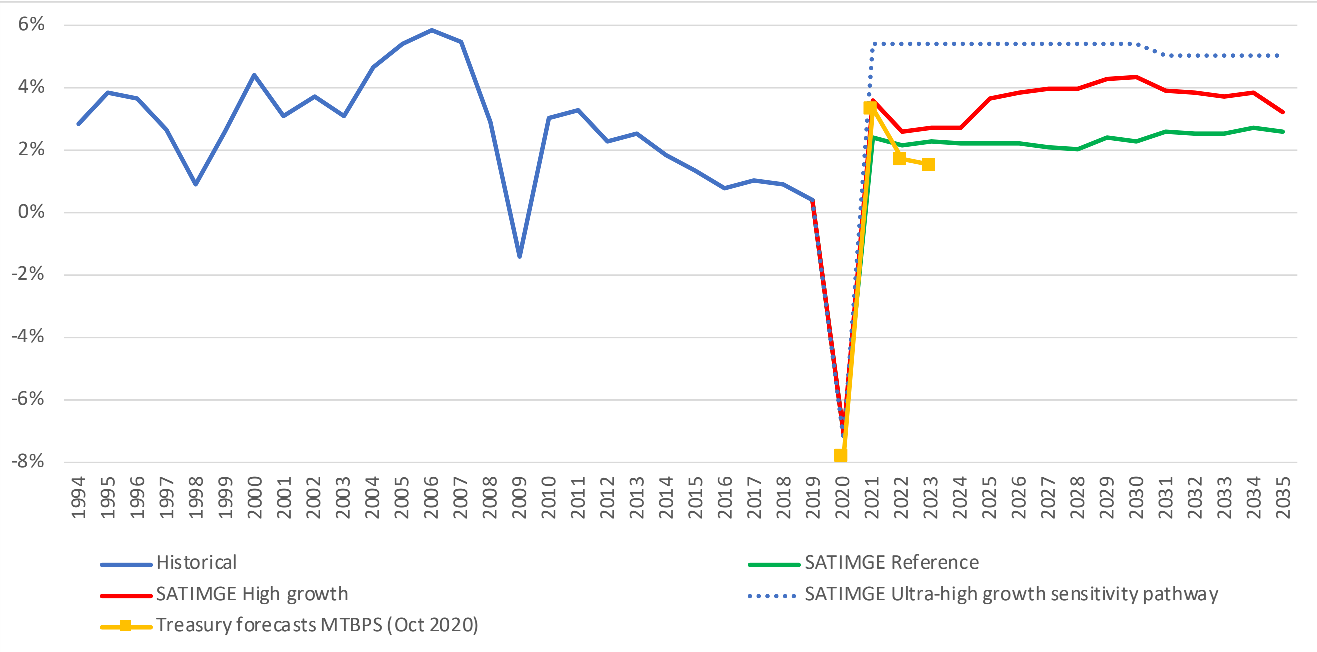

Figure 7 - Historical and projected GVA growth rates, along with Treasury's short-term forecast.

An ultra-high growth scenario is also considered, based on discussions with DEFF, which considers a growth rate of 5.4% from 2021 to 2030, and which declines thereafter. This is a very unlikely outcome, and this has been modelled as a sensitivity analysis to show the impact on emissions of very high growth in the 2020s, and to indicate the risk of not meeting a specific NDC target if economic growth happened to reach these levels. This scenario is based on the economic growth rate required by the National Development Plan (NPC 2011) (which required average economic growth of 5.4% from 2011-2030 to achieve its development goals). After this it declines gradually (0.5% per five years) to 3.5% by 2050. This growth rate has been modelled purely in SATIM (and not in the CGE model) to explore the impact on emissions of very high growth rates in the 2020s. It has to be emphasised that this very high growth rate is not based on current literature on growth outlooks for the South African economy, or on any growth-oriented policies and/or measures currently proposed by government.

These two growth scenarios, and the very high growth scenario, are presented in Figure 7 above[2]. The figure presents the growth rate in Gross Value Added (total value added at basic prices) for 1994-2035. Values for 2016-2019 are historical values sourced from StatsSA (StatsSA 2020b). Average growth rates are presented in Table 3 below. These two growth rates are referred to in this way in all subsequent sections below – as "reference" and "high" growth rates.

[2] It is important to note that these growth rates are as implemented in the SATIMGE modelling framework for scenarios without any policy interventions. Economic growth is affected in the modelling framework by the implementation of policies and measures, and so will deviate for all other scenarios. The economic growth impact of policies and measures is reported on in detail in the results section.

Table 3 - Average GVA growth rates

	Reference	High growth	Ultra-high growth
2016-19	0.8%	0.8%	0.8%
2020	-7.2%	-7.2%	-7.2%
2021 recovery	2.4%	3.6%	5.4%
2021-5	2.2%	3.0%	5.4%
2026-30	2.2%	4.1%	5.4%

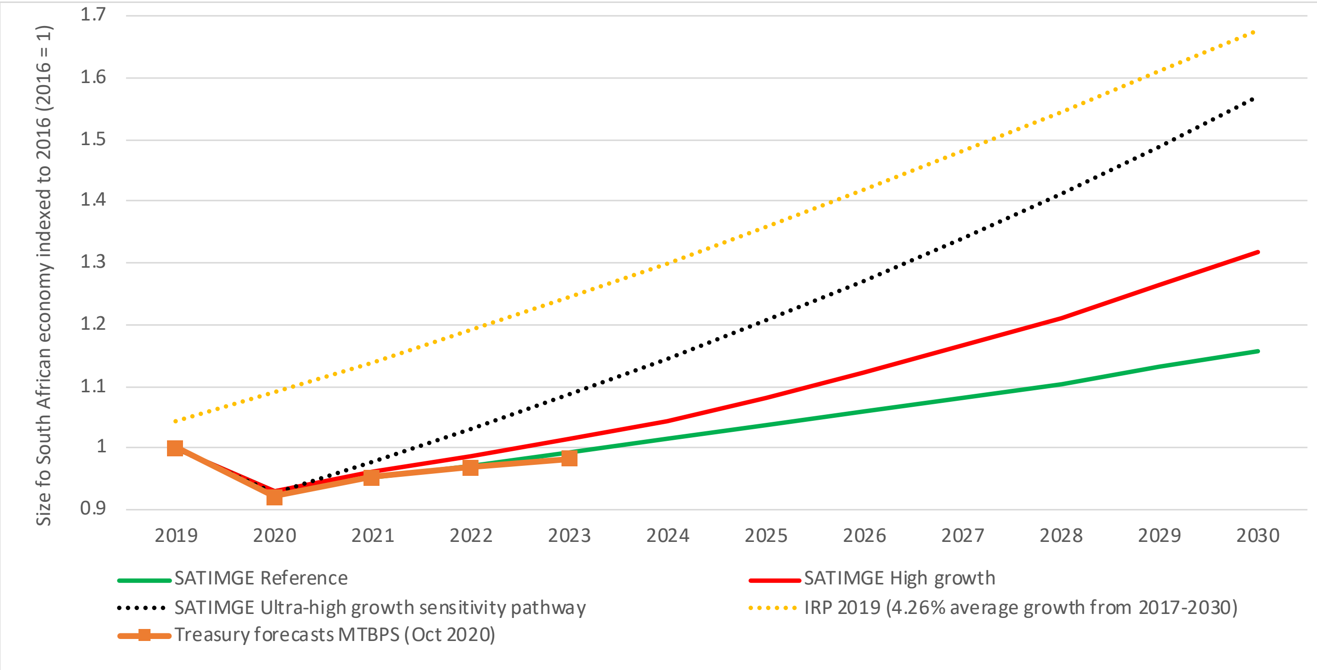

Figure 8 - Size of the South African economy relative to its 2019 size as a result of the Treasury's post-COVID projection and modelled economic growth paths to 2030

Figure 8 above presents the resulting size of the economy. After the contraction of the economy in 2020 due to the COVID crisis, the economy only reaches its 2019 size again in 2024 in the reference scenario, and in 2023 in the high growth scenario. Both the National Treasury and South African Reserve Bank growth projections follow in the short term (to 2023) the reference growth scenario, with the Treasury projection being slightly more pessimistic. Both the IRP 2019 projection and the ultra-high growth pathway result in the economy growing by around 1.6 times its 2019 size by 2030, whereas the reference growth scenario results in the economy growing by under 1.2 times its 2019 size, and the high growth scenario results in the economy growing by slightly over 1.3 times by 2030.

2.1.3 Calibration with the 2017 South African GHG Inventory

A detailed comparison was undertaken between GHG emissions estimates and information sources used in SATIMGE GHG values per IPCC category and the values in the South African National GHG inventory Report (NIR) for the year 2017, the latest available at the time, in consultation with DFFE's GHG inventory team. The comparisons were undertaken with the draft 2017 GHG inventory published for comment in 2020. The values contained in the comparison are the revised final values to be used in the 2017 NIR, as presented in Table 4 below.

Table 4 - Comparison between GHG estimates per IPCC category in SATIMGE and the 2017 South African GHG inventory

IPCC Category	SATIMGE	2017 GHG inventory
1 Energy	382,990	410,685
2 Industrial Processes and Product Use	41,567	32,085
3 AFOLU	17,740	17,998
4 Waste	22,277	21,249
TOTAL with land use	**464,574**	**482,016**
TOTAL without land use	**495,256**	**512,661**

A detailed comparison of significant differences is presented in Figure 9 below. There are two kinds of differences to note. The first arises due to different classifications (into IPCC categories) of GHG emissions estimates. In the case of category 1A5, emissions from non-transport use of liquid fuels (mainly in mining) in the NIR are contained in this category, whereas in SATIMGE these are contained in category 1A2. Emissions from utilities at the Sasolburg chemicals complex are contained in category 1A1c in the NIR (since these are reported jointly with emissions from the coal-to-liquids plant at Secunda, also owned by Sasol), whereas these are contained in category 1A2 (manufacturing) in SATIMGE. Emissions from autogeneration electricity plant are contained in category 1A1a in the NIR, whereas these are contained in category 1A2 in SATIMGE.

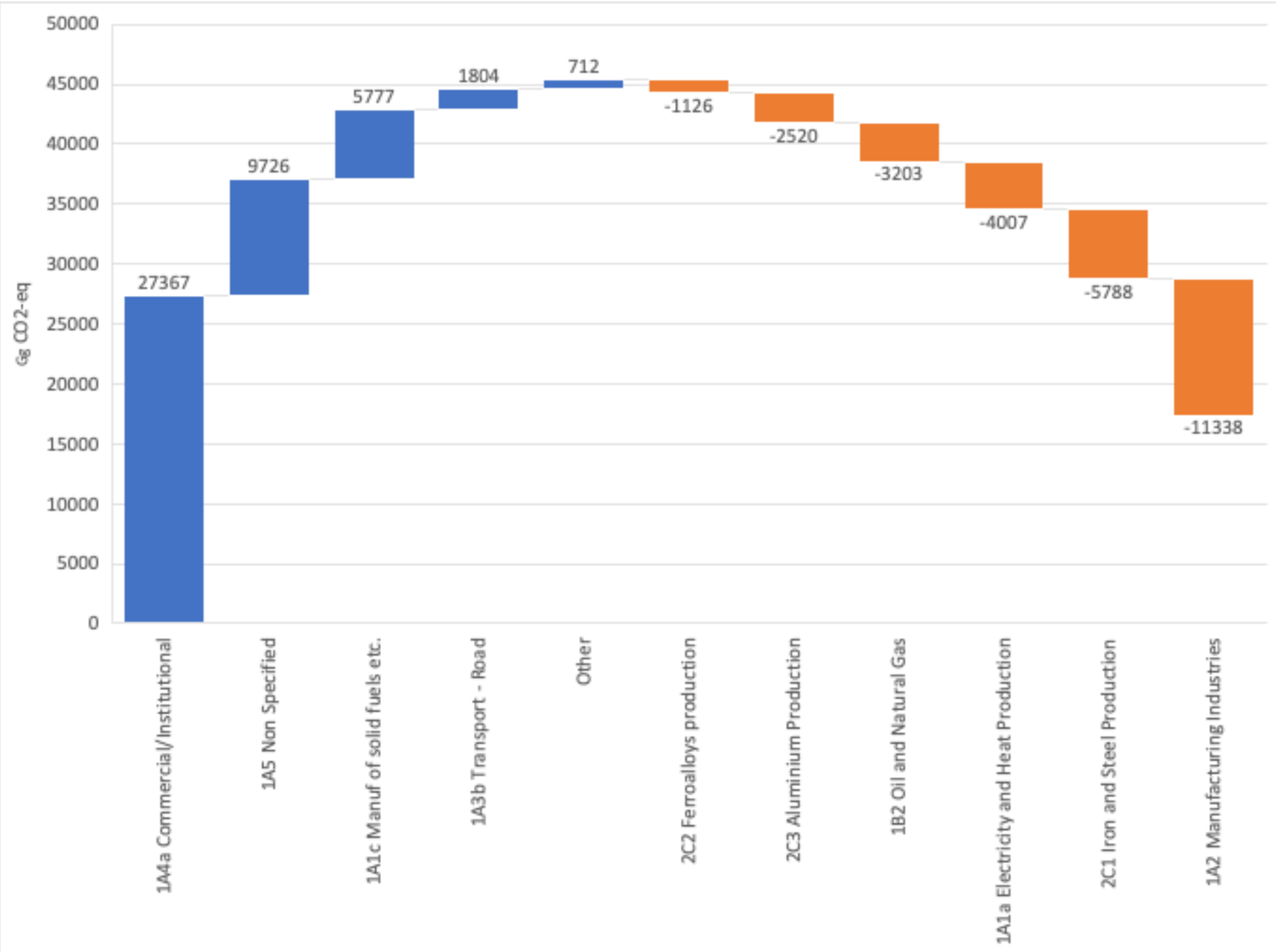

Figure 9 - Detailed comparison of significant differences by IPCC category between GHG estimates in SATIMGE and the 2017 South African GHG inventory for the year 2017. Blue implies that NIR estimates are greater than SATIMGE values; orange implies the converse.

The second difference consists of differences in estimation, arising from the use of different methodologies and/or data sources. Where these differences were maintained in SATIMGE after consideration of the estimation methodology and data sources (and the relevant IPCC guidelines), SATIMGE estimates were considered by the project team to be more accurate, with some exceptions, noted below. For IPPU emissions, the NIR estimates (amended after draft released for public comment) were revised to reflect data gathered on actual emissions submitted in terms of the GHG reporting regulations, after the finalisation of the SATIMGE calibration process. This has resulted in reductions in the estimations of IPPU emissions in the final version of the NIR, which are not reflected in SATIMGE. In the case of road transport emissions, SATIMGE emissions were calibrated with DMRE data on liquid fuels sales, and allocation to different fuel applications was made using a revised energy balance and a vehicle parc model. Estimates are close to those in the NIR (with a difference of approximately 1 Mt).

The biggest difference, of 27.3 Mt, is in the commercial sector. The estimate in the NIR for the commercial sector was arrived at via the allocation of the remainder of total national coal sales (contained in the SAMI 2017/18 report (Mineral Economics Directorate 2019)), and which could not be allocated elsewhere) between sectors, rather than as a result of actual data on coal use in the commercial sector. The estimate in SATIMGE is based on an assumed average coal price, and data on coal purchases by the commercial sectors in the StatsSA supply and use tables for 2014 , as well as available studies on coal use in the commercial sector, and the national energy balance.

These differences result in a net difference of around 17 Mt between the NIR and SATIMGE estimates. As a result of these differences, a margin of error of 20 Mt has been assumed for GHG inventory estimation in the accounting for South Africa’s NDC targets.

2.1.4 Modelling – use of SATIMGE, waste and AFOLU modelling

GHG emissions, and other relevant indicators, were modelled using SATIMGE, which consists of the South African TIMES model (SATIM) hard-linked to ESAGE, a variant of the South African General Equilibrium CGE model with a more granular energy sector. Both models, as well as the linked modelling framework, are maintained by the Energy Systems Analysis Group at the University of Cape Town. SATIMGE now includes all sectors of the economy and all IPCC emissions categories contained in the South African NIR with the inclusion of waste and AFOLU emissions. All results discussed below were modelled using this integrated framework, and were modelled over a time horizon from 2012 to 2050. Results have however been reported to 2035, to focus on the key target years of the NDC of 2025 and 2030.

2.1.5 Differences in Global Warming Potentials and accounting with/without natural disturbances

There are two important methodological differences between estimation methods currently used in the national GHG inventory (and in SATIMGE), and the way in which South Africa’s NDC targets will be accounted for in 2025 and 2030.

The first of these is in the use of different Global Warming Potential (GWP)[3] values. Currently the South African GHG inventory uses GWP values from the IPCC’s Second Assessment Report (SAR), as required of developing countries by the relevant UNFCCC decision. When biennial reporting begins under the Paris Agreement in 2024 (for both developed and developing countries), all countries are required to use GWP values from the IPCC’s Fifth Assessment Report (AR5), which are higher than the SAR values. These are the GWP values which South Africa will use in accounting for the achievement of its NDC targets in 2025 and 2030, and use of these values will result in national GHG estimates which are 2.8-3% or 13 Mt higher (based on modelled GHG emissions for 2025 and 2030 for GHGs reported in the current GHG inventory).

The second is the decision by DFFE to exclude GHG emissions from natural disturbances in accounting for its NDC target. More detailed information on GHG emissions from natural disturbances is provided in section

[3] Different GHGs (for instance methane, nitrous oxide) have different global warming effects, and different lifetimes in the atmosphere. In order to compare the impact of different GHGs, GWPs are used to convert the mass of each GHG into the equivalent amount of CO_2 which would have the same global warming impact over a specified time period. The time period used in most cases is 100 years. Therefore, for example, over a 100-year period, 1 ton of methane has the same global warming impact as 21 tons of CO_2 (Second Assessment Report). Literature on GWPs is reviewed as part of the IPCC’s assessment process, every five years or so, in the light of the latest science on the relative warming impact of different GHGs. The UNFCCC has therefore adopted these assessed GWP values from specific IPCC Assessment Reports, to make GHG inventories as comparable as possible.

2.3.7.1 and in Figure 38 below. The rationale for the exclusion of these GHG emissions is that these have high interannual variation – in other words, these emissions fluctuate unpredictably from year to year. The main source of emissions from natural disturbances in South Africa are wild fires. Including these emissions in South Africa's NDC target could eclipse the impact of mitigation measures, and mask an underlying trend of GHG emissions reduction, since these emissions fluctuate from 10 to 30 Mt CO_2-eq each year. Estimations of GHG emissions for accounting for the achievement of South Africa's NDC in targets years will then be 10-30 Mt lower than they would have been. This offsets the rise in emissions as a result of the shift in GWP values.

In the results presented below, unless otherwise stated, SAR GWPs have been used, and natural disturbances have been included in GHG emissions totals.

2.1.6 Scenarios / policies modelled

Four basic scenarios have been modelled – a combination of two economic growth rates (reference and high, as outlined above), and two policy scenarios. These are presented in Table 5 below. The first policy scenario - the "Existing policies" scenario, only contains policies/measures/programmes which are already being implemented. The second policy scenario – the "Planned policies" scenario, consists of these plus policies/measures/programmes which are currently being planned, but have not been implemented as yet. Each of these basic scenarios is modelled with the two economic growth rates outlined above (reference and high growth rates), and a series of sensitivity analyses was also conducted on key variables. Policies modelled in each scenario are described below.

Table 5 - Basic scenario matrix

	Existing policies	**Planned policies**
Reference GDP growth	Existing policies with reference economic growth rate	Planned policies with reference economic growth rate
High GDP growth	Existing policies with high economic growth rate	Planned policies with high economic growth rate

2.1.6.1 Existing policies scenario

In this scenario, in most instances the modelling framework meets demand in the most cost-effective way possible. In the electricity sector, committed projects as specified in the IRP 2019 are completed as specified in Table 6 below and described in the section below; and any further electricity supply investments are determined by the modelling framework on a least-cost basis. Existing power plants retire as specified in the IRP 2019, and the availability factors of Eskom's plants are assumed to be the same as in IRP 2019. In the liquid fuels sector, it is assumed, in line with government pronouncements, that a new world-scale crude refinery comes online in 2028[4]. Other crude refining capacity is assumed to be available until 2050, as is the existing coal-to-liquids capacity. Existing gas-to-liquid capacity is assumed to retire in 2024. No specific energy efficiency or transport policies are assumed. In the transport sector, there is no further modal shifting in either the freight or passenger sector, but new transport technologies are invested in by the model as a result of falling technology costs and rising oil prices.

In the waste sector, it is assumed that the modernisations introduced by the 1st and 2nd National Waste Management Strategy are maintained.

2.1.6.2 Planned policies scenario

Planned policies/measures/programmes which have been modelled include the following:

- IRP 2019 in the electricity sector
- The Green Transport Strategy
- The draft post 2015 National Energy Efficiency Strategy

[4] A decision to include the new refinery in all scenarios was made after consultation with DFFE.

- The Carbon Tax

The expansion plan for IRP 2019 has been implemented as stated in Table 6 (committed capacity) and Table 7 (new capacity) (DMRE 2019), with the following caveats, which have been highlighted in yellow in the tables:

- The 750 MW of planned coal capacity which is scheduled in the IRP to begin operation in 2023 has been shifted to 2026, to allow sufficient lead time for auctioning, contracting, construction etc.
- The new wind power capacity which is due to begin coming online from 2022, have been shifted back to the latter half of 2023 to allow sufficient time for auctioning, contracting, construction etc. This means that 800 MW of wind capacity comes online in 2023, followed by 1600 MW per year as specified in the IRP, until 2030. The additional wind capacity is added after 2030.
- 1000 MW of new natural gas capacity which is scheduled to begin operation in 2024 has been shifted to 2026.
- The "other" category" is occupied in the unspecified years from 2019 to 2022 by 1500 MW of on-site PV, and the 500 MW/year in this category is assumed to be taken up with on-site PV until 2030.
- The committed capacity (Medupi and Kusile, REIPPPP wind, solar) – Medupi and Kusile units come onto the grid according to an updated schedule contained in Eskom's 2019 Medium Term System Adequacy Outlook, and the timing of REIPPPP project's connection to the grid were reassessed using updated estimates from www.energy.org.za. For solar thermal, 400 MW was assumed to have been connected by 2018 and 100 MW only was added in 2019 (as opposed to 300 MW being connected by 2018 and 300 MW in 2019).

Table 6 - Committed capacity in the IRP 2019 and in SATIMGE for this analysis, contained in both the Existing and Planned policies scenarios; differences are highlighted in yellow.

	2019	2020	2021	2022	2023
Coal IRP 2019	2155	1433	1433	711	0
Coal SATIMGE	722	2166	1444	722	722
PV IRP 2019	0	114	300	400	0
PV SATIMGE	0	114	300	400	0
Wind IRP 2019	244	300	818	0	0
Wind SATIMGE	0	244	300	818	0
CSP IRP 2019	300	0	0	0	0
CSP SATIMGE	100	0	0	0	0

The differences between the new build plan in the IRP 2019 and the new build plan in the Planned policies scenario are presented in Table 7 below.

Table 7 - New build in IRP 2019's Table 5 compared to the way it has been included in the Planned policies scenario; differences are highlighted in yellow.

		2022	2023	2024	2025	2026	2027	2028	2029	2030
Coal	IRP 2019	0	750	0	0	0	750	0	0	0
	Planned policies scenario	0	0	0	0	750	750	0	0	0
Hydro	IRP 2019	0	0	0	0	0	0	0	0	2500
	Planned policies scenario	0	0	0	0	0	0	0	0	2500
Storage	IRP 2019	513	0	0	0	0	0	0	1575	0
	Planned policies scenario	513	0	0	0	0	0	0	1575	0
PV	IRP 2019	1000	1000	0	1000	0	0	1000	1000	1000
	Planned policies scenario	1000	1000	0	1000	0	0	1000	1000	1000

Wind	IRP 2019	1600	1600	1600	1600	1600	1600	1600	1600	1600
	Planned policies scenario	0	800	1600	1600	1600	1600	1600	1600	1600
Gas / Diesel	IRP 2019	0	0	1000	0	0	2000	0	0	0
	Planned policies scenario	0	0	0	0	1000	2000	0	0	0
Other	IRP 2019	-	500	500	500	500	500	500	500	500
	Planned policies scenario	450	500	500	500	500	500	500	500	500

It should be emphasised that the electricity demand in IRP 2019 is NOT the same as the resulting electricity demand contained in the results below. Because SATIMGE is an economy-wide modelling framework, the electricity demand is endogenous. The resulting electricity demand is compared to that of the IRP in the section on modelled GHG emissions below. Generally, it is significantly lower than the assumed electricity demand in the IRP due to lower economic growth rates than those underlying the demand projections used in the IRP (these are presented above in the discussion of economic growth rates).

The Green Transport Strategy (GTS) (DoT 2018) consists of a number of long-term qualitative goals, and a number of very ambitious quantified short-term goals. These have been implemented conservatively in the current analysis as follows:

- A shift from road to rail for corridor freight transport. By 2030, the rail share of corridor freight transport will be 30%, and by 2050, 50%.
- A shift from private to passenger transport. A 20% relative shift to public transport by 2030.
- Alternative vehicles. A minimum of 10% of the vehicle population will comprise EVs and hybrid vehicles by 2030, reaching 40% by 2050.
- Minibus conversion to bifuel (CNG/petrol) vehicles. 10% of the minibus taxi fleet will be converted to be bifuelled by 2030, reaching 40% by 2050.
- Metrobus to gas. 10% of the municipal bus fleet will be converted to gas by 2030, reaching 30% by 2050.

The GTS also contains references to biofuels – 2% blending with petrol and 5% blending with diesel by 2030 have also been included in the Planned policies scenario.

Energy efficiency measures modelled in the Planned policies scenario are, in the absence of a finalised energy efficiency policy and/or strategy, based on the draft post-2015 National Energy Efficiency Strategy (NEES) (DoE 2016), which proposes sectoral targets for 2030. These are included as follows:

- Residential. A 30% improvement in the efficiency of household energy appliances by 2030, and a 20% improvement in the energy efficiency of residential buildings is achieved by 2030.
- Commercial. A 37% reduction in energy intensity in commercial buildings, including government buildings, by 2030.
- Mining. The 40 PJ savings identified by the NEES translates into a 4% energy savings by 2030.
- Manufacturing. 35% improvement in energy efficiency in all applications other than furnaces and kilns, which improve by 5%, by 2030.

The carbon tax is modelled as being implemented at a nominal rate of R120/ton in 2019, rising as per the Carbon Tax Act to R127.3 (in 2019 Rands) by 2022, and remaining at that level in real terms thereafter. The effective tax rate (after allowances) is R31.8/ton after 2022.

No planned policies for mitigation were found in the agriculture sector for non-energy emissions, and so there is no mitigation modelled in this sector. In the land sector, a number of measures were modelled as follows:

- Forest, woodland and grassland rehabilitation, and thicket restoration as contained in the DAFF 2015/16 to 2018/19 Strategic Plan (DAFF, 2015a), the Land Degradation Neutrality Targets (LDNT) and in DAFF's Draft Climate Change Sector Plan ;
- Replanting of temporarily unplanted plantations as contained in the DAFF 2015/16 to 2018/19 Strategic Plan;

- Restoration of agricultural land as contained in the DAFF 2015/16 to 2018/19 Strategic Plan;
- Conservation agriculture measures contained in the Conservation Agriculture Policy for DAFF
- Afforestation measures contained in DAFF's Draft Climate Change Sector Plan;
- In the waste sector, it is assumed that the targets in the 3rd National Waste Management Strategy are achieved, for waste minimisation, further increases in recycling targets, and diversion of organic waste from landfill.

2.1.6.3 Parameters and specifications for sensitivity analyses

A number of additional variations on the four basic scenarios outlined above were also modelled, to explore the impact of various key assumptions, as follows

- **Ultra high economic growth.** As described previously, a growth rate of 5.4% (from 2021) was modelled, aligned with the NDP. This growth rate is extremely unlikely to occur, but the sensitivity analysis does provide a hypothetical outer bound for GHG emissions growth. The growth rate was modelled for both the policy scenarios.
- **Implementation of the planned policies above, without the implementation of IRP 2019.** The planned policies above were modelled without IPR 2019 (the model simply chooses least-cost investments in the electricity sector) to assess the mitigation impact of the planned policies above without the IRP.
- **IRP 2019 with no other planned policies.** This case was modelled to assess the mitigation impact of the IRP without the implementation of any of the other above planned policies.
- **More or less ambitious implementation of planned policies.** Two additional cases were modelled with more ambitious and less ambitious implementation of planned policies. Variation in implementation targets in these cases is contained in Table 9 below. The "less ambitious" column specifies lower versions of each policy and/or measure, and the "more ambitious" column specifies more ambitious versions of each policy and/or measure modelled in the Planned policies scenario.

Staged capacity variants of IRP 2019. Two scaled-back investment plans were modelled, based on IRP 2019, which are presented in detail in

- Table 10 below. Both plans *exclude* new hydro and coal capacity, and increase the annual rate of investment in renewable energy technology more slowly. Over the 2019-2030 period, the "medium RE" plan contains 1900 *less* MW of wind power and 500 *more* MW of PV, no new coal or hydroelectricity plants, and storage/OCGT plants as required. The "low RE" plan contains 6600 MW less wind and 100 MW less PV.
- **Low oil price**. A sensitivity analysis was run to determine the impact of a lower oil price on the energy transition in the transport sector (from internal combustion engines to alternative technologies(hybrid/energy vehicles). The oil price in SATIMGE is taken from the IEA's 2019 World Energy Outlook (IEA 2019), and is assumed to be USD62 in 2020 and USD105 in 2030, corresponding to the IEA WEO's "Current Policies" scenario. The sensitivity analysis used an oil price of USD62 in 2020 and USD 60 in 2030, corresponding to the IEA's "Sustainable Development" scenario.
- **Lower Energy Availability Factor.** The EAFs for Eskom's coal plants were assumed to be those contained in IRP 2019, in Table 6. These have proved to be overoptimistic compared to actual EAFs for Eskom coal plants in 2019 and 2020, which has also contributed to current load-shedding. A sensitivity analysis was therefore run using lower EAFs based on (Wright and Calitz 2020). The default and lower average EAFs for Eskom's coal fleet are contained in Table 8 below.

Table 8 - Average EAFs for Eskom's coal plants (weighted by capacity)

	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Default EAF	68%	69%	71%	71%	72%	73%	72%	72%	72%	73%	72%
Lower EAF	61%	61%	62%	61%	60%	61%	60%	60%	60%	60%	59%

Table 9 – Less and more ambitious policies and measures specified by sector and policy/measure.

Sector	Policies / Measures	Less ambitious	Planned policies scenario	More ambitious
Transport	Freight transport shift from road to rail – more ton kms transported by rail	20% share of corridor freight transported by rail by 2030	30% share of corridor freight transported by rail by 2030	30% share of corridor freight transported by rail by 2030
		20% relative shift to public transport by **2050** – in other words 20% less passenger km travelled in private vehicles than in the "Existing policies" case	20% relative shift to public transport by **2030** – in other words 20% less passenger km travelled in private vehicles than the "Existing policies" case	20% relative shift to public transport by **2030** – in other words 20% less passenger km travelled in private vehicles than in the "Existing policies" case
	New vehicle technologies	At least 10% of the vehicle population to hybrid vehicles by 2030. Cost parity for electric vehicles with internal combustion engine vehicles by 2040.	At least 10% of the vehicle population to comprise electric vehicles and/or hybrid vehicles by 2030. Cost parity for electric vehicles with internal combustion engine vehicles by 2030.	At least 10% of the vehicle population to comprise electric vehicles and/or hybrid vehicles by 2030. Cost parity for electric vehicles with internal combustion engine vehicles by 2030.
	Minibus taxi conversion to bifuel (CNG/petrol).	10% of the minibus fleet converted to be bifuelled by 2050.	10% of the minibus fleet converted to be bifuelled by 2030.	10% of the minibus fleet converted to be bifuelled by 2030.
	Metrobus to CNG conversion.	10% of the municipal bus fleet converted to CNG by 2050.	10% of the municipal bus fleet converted to CNG by 2030.	10% of the municipal bus fleet converted to CNG by 2030.
Residential	Post-2015 National Energy Efficiency Strategy – residential appliance efficiency improvement.	20% improvement in household appliance end use efficiency, including coal and wood stoves.	30% improvement in household appliance end use efficiency, including coal and wood stoves.	30% improvement in household appliance end use efficiency, including coal and wood stoves.
	Post-2015 National Energy Efficiency Strategy – building design improvements to reduce specific energy demand for lighting, space heating and cooling.	A 13% reduction in specific energy demand by 2030.	A 20% reduction in specific energy demand by 2030.	A 20% reduction in specific energy demand by 2030.
Commercial	Post-2015 National Energy Efficiency Strategy – Improvement in the energy efficiency of buildings in the commercial sector.	A 25% reduction in specific energy consumption in commercial buildings by 2030.	A 37% reduction in the specific energy consumption in commercial buildings by 2030.	A 37% reduction in the specific energy consumption in commercial buildings by 2030.

	Post-2015 National Energy Efficiency Strategy – improvements in the energy intensity of street lighting and water pumping in local authorities.	No improvement.	20% improvement in efficiency by 2030.	20% improvement in efficiency by 2030.
Industry	Post-2015 National Energy Efficiency Strategy – energy efficiency in the mining sector.	2% savings by 2030, based on the NEES target of 40PJ savings by 2030, saved on electrical end uses in mining.	4% savings by 2030, based on the NEES target of 40PJ savings by 2030, saved on electrical end uses in mining.	4% savings by 2030, based on the NEES target of 40PJ savings by 2030, saved on electrical end uses in mining.
	Post-2015 National Energy Efficiency Strategy – energy efficiency in the manufacturing sector (excluding furnaces and kilns)	17% improvement by 2030, compared to the Existing policies scenario.	35% improvement by 2030, compared to the Existing policies scenario.	35% improvement by 2030, compared to the Existing policies scenario.
	Post-2015 National Energy Efficiency Strategy – energy efficiency in the manufacturing sector (furnaces and kilns)	2.5% improvement by 2030	5% improvement by 2030	5% improvement by 2030
Cross-cutting	Carbon tax	R120 in 2019, reaching R127.3 (in 2019 Rands) in 2022, and remaining at that level in real terms thereafter, with an effective tax rate of R31.8/ton Single average allowance of 75%.	R120 in 2019, reaching R127.3 (in 2019 Rands) in 2022, and remaining at that level in real terms thereafter, with an effective tax rate of R31.8/ton Single average allowance of 75%.	R120 in 2019, reaching R127.3 (in 2019 Rands) in 2022, and escalating to an effective tax rate of R159.1 (2019 Rands) by 2030. Phaseout of allowances entirely by 2030.)

Table 10 - New capacity in the electricity sector by technology for the Planned policies scenario, and the medium RE and low RE sensitivity analyses, in MW.

	2022	2023	2024	2025	2026	2027	2028	2029	2030
Coal Planned policies	0	0	0	0	750	750	0	0	0
Coal medium RE	0	0	0	0	0	0	0	0	0
Coal low RE	0	0	0	0	0	0	0	0	0
Wind Planned policies	0	800	1600	1600	1600	1600	1600	1600	1600
Wind medium RE	0	800	900	1000	1200	1400	1600	1600	1600
Wind low RE	0	400	450	550	600	700	800	900	1000
Solar PV Planned policies	1000	1000	0	1000	0	0	1000	1000	1000
Solar PV medium RE	0	500	600	700	800	900	1000	1000	1000
Solar PV low RE	0	450	500	550	600	650	700	750	800
Hydro Planned policies	0	0	0	0	0	0	0	0	2500

Hydro medium RE	0	0	0	0	0	0	0	0	0
Hydro low RE	0	0	0	0	0	0	0	0	0
On Site PV Planned policies	450	500	500	500	500	500	500	500	500
On Site PV medium RE	450	500	500	500	500	500	500	500	500
On Site PV low RE	226	250	250	250	250	251	250	250	250

2.2 Economy-wide GHG emissions in 2025 and 2030

2.2.1 "Existing policies" GHG emissions

GHG emissions from 2017 to 2035 are presented in Figure 10 below. After a decline in emissions in 2020, emissions grow by 20-50 Mt to 2030, and even in the ultra-high economic growth case, do not grow beyond 540 Mt CO2-eq.

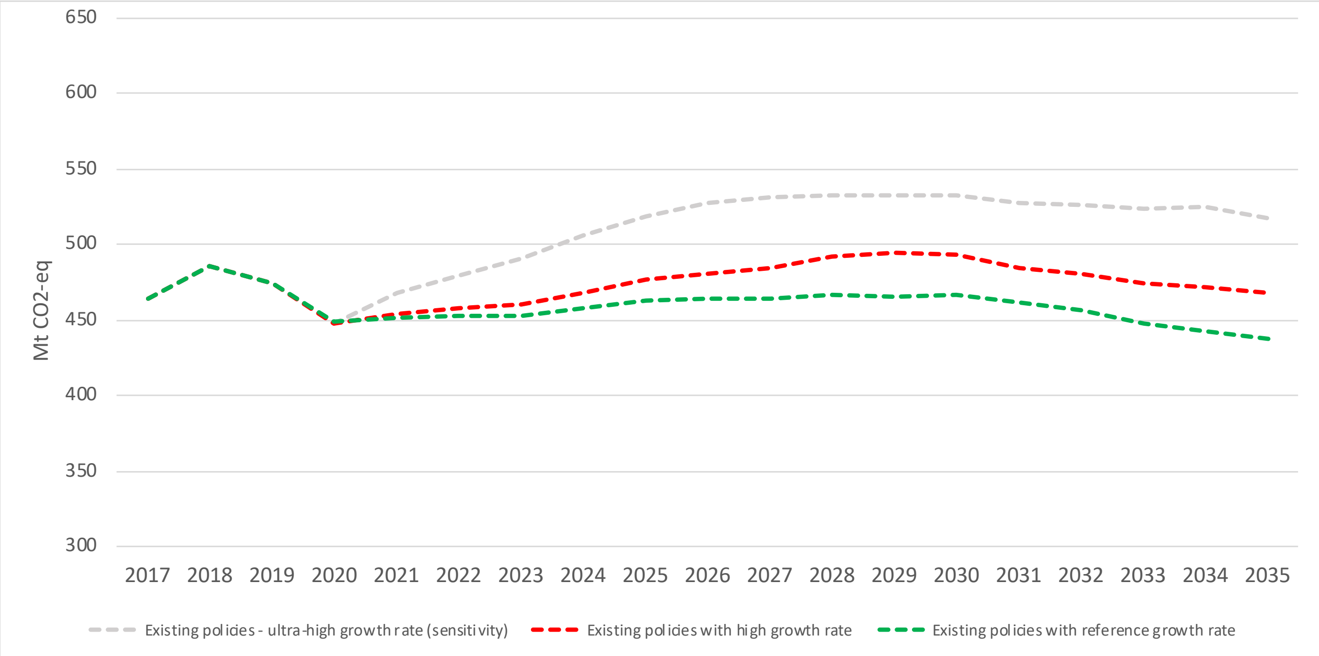

Figure 10 - GHG emissions for the Existing policies scenario with reference, high and ultra-high growth rates

Figure 11 below presents the GHG emissions intensities for these cases indexed to 2017. The fluctuation in 2018 is due to an increase in land use emissions in that year (see section 2.3.7 below). The steady decline in emissions intensity is mainly due to energy transitions taking place in the electricity and transport sectors, as well as a slow change in the structure of the economy towards less energy-intensive sectors. A faster decline in emissions intensity with economic growth is due to two factors: i) some sub-sectoral sources of emissions do not grow faster or at all with economic growth (for instance, coal-to-liquids output does not change with economic growth), and ii) the energy transition, especially in the electricity sector, takes place faster with higher economic growth rates, since the stock of high-carbon infrastructure (in the case of the electricity sector, coal plants) does not increase, whereas faster economic growth results in higher investment in low- or zero-carbon infrastructure (in the case of the electricity sector, in renewable energy technologies).

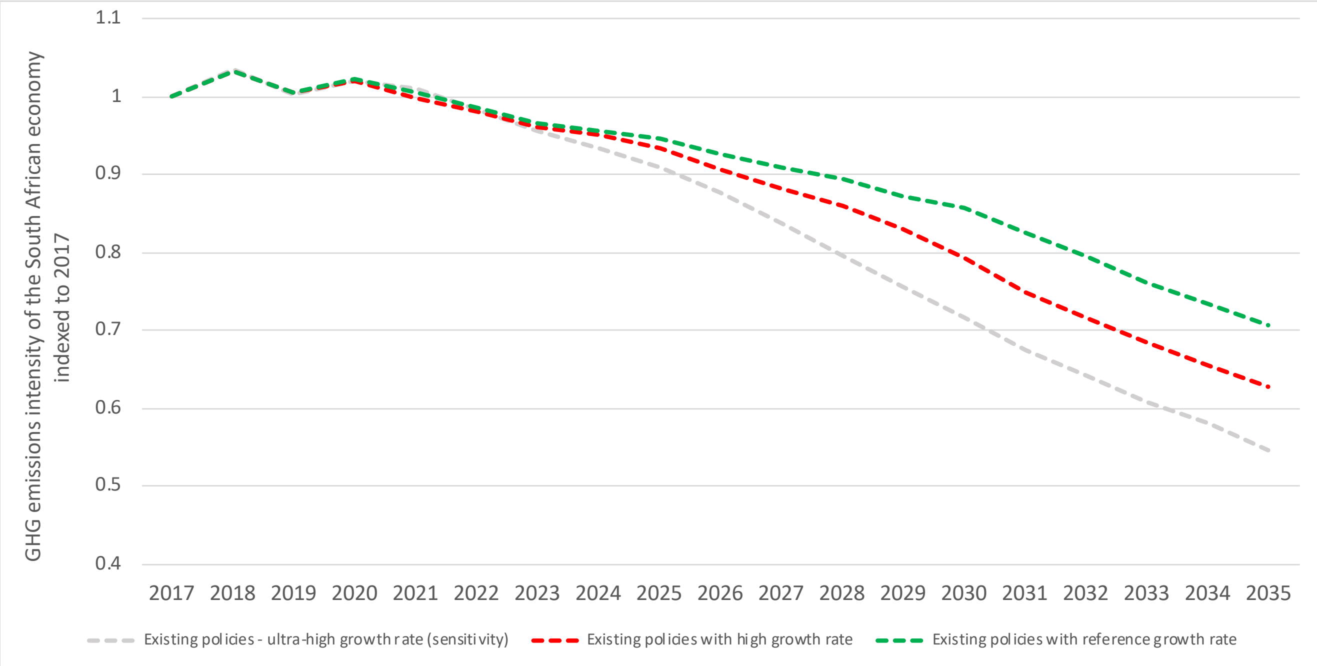

Figure 11 - GHG emissions intensity (GHG/GVA), indexed to 2017, for the Existing policies scenario, with reference, high and ultra-high growth rates

2.2.2 "Planned policies" GHG emissions

With the addition of the policies and measures referred to in section 2.1.6.2 above, GHG emissions would drop by approximately 100 Mt by 2030, as presented in Figure 12 below.

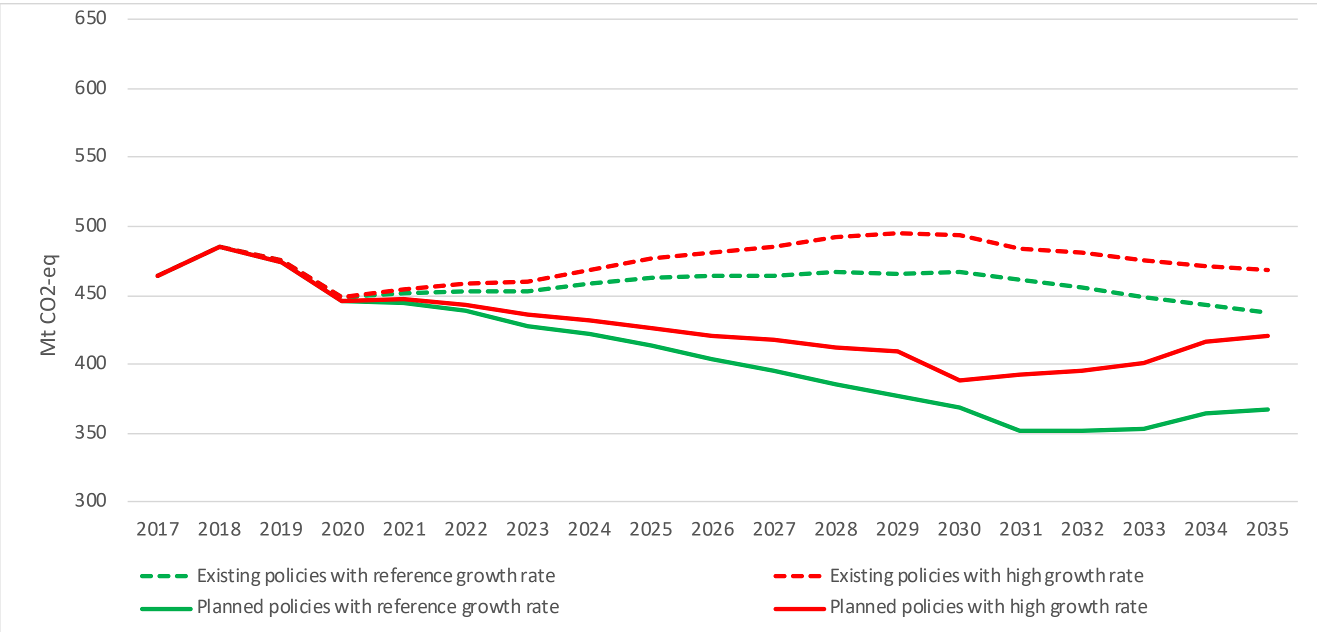

Figure 12 - GHG emissions for the Existing and Planned policy scenarios, with reference and high economic growth rates

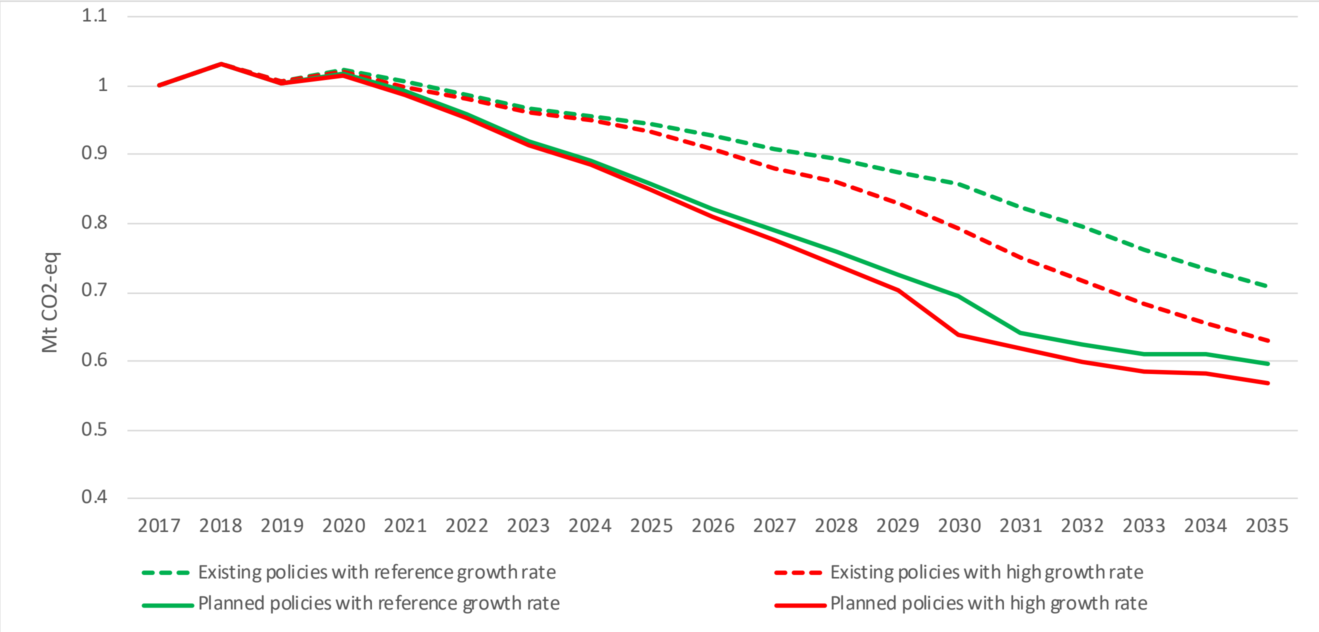

Figure 13 - GHG emissions intensity (GHG/GVA), indexed to 2017, for the Existing and Planned policies scenarios, with reference and high growth rates

The increase in GHG emissions after 2030 is due to the nature of the IRP 2019, which only specifies new capacity until 2030. After 2030, because of lower electricity demand, there is less investment in renewable energy after 2030 and more utilization of Eskom coal plants. This may not be the case with a lower EAF than that assumed in the IRP, and with a consistent renewable energy investment plan after 2030.

Figure 13 above presents GHG emissions intensities for both the Existing policy and Planned policy scenarios, with reference and high growth rates. As expected the Planned policy scenario causes a more rapid reduction in emissions intensity which stabilizes in the 2030s for the reasons outlined above. Further expansion of renewable energy would result in further drops in emissions intensity.

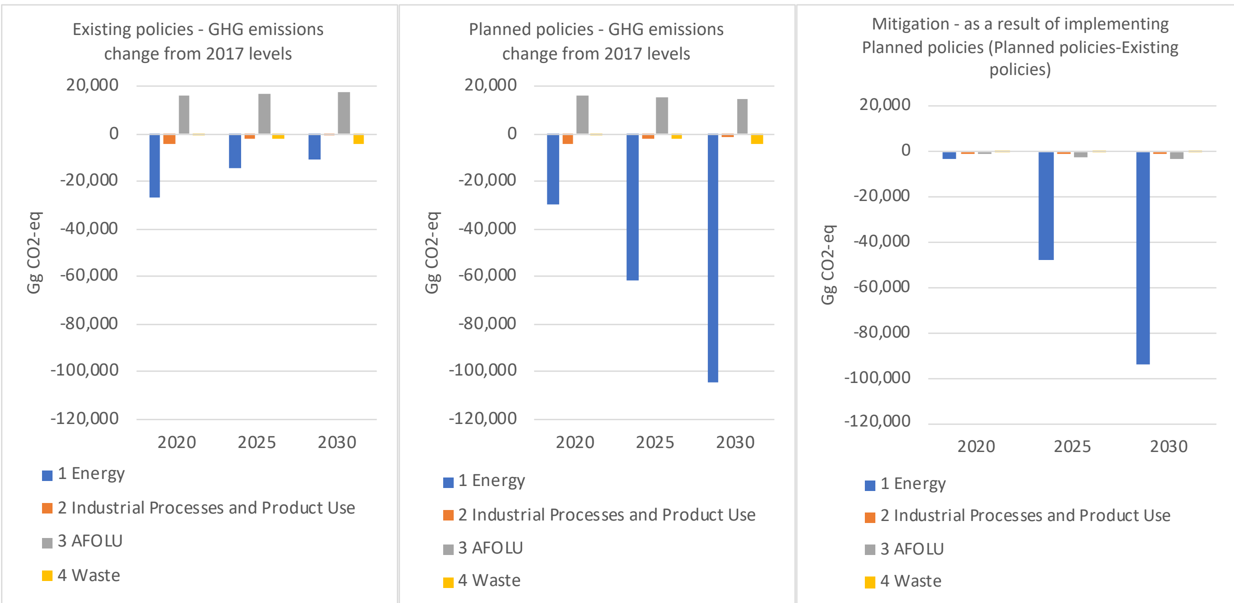

Figure 14 - Change in GHG emissions for the main IPCC categories for the Existing policies scenario (reference growth) from 2017 levels (left), the Planned policies scenario (reference growth) from 2017 levels (middle), and the difference in GHG emissions per IPCC sector between the Existing policies and Planned policies scenarios (reference growth) (right) – i.e. the mitigation effect of the Planned policies scenario in relation to the Existing policies scenario.

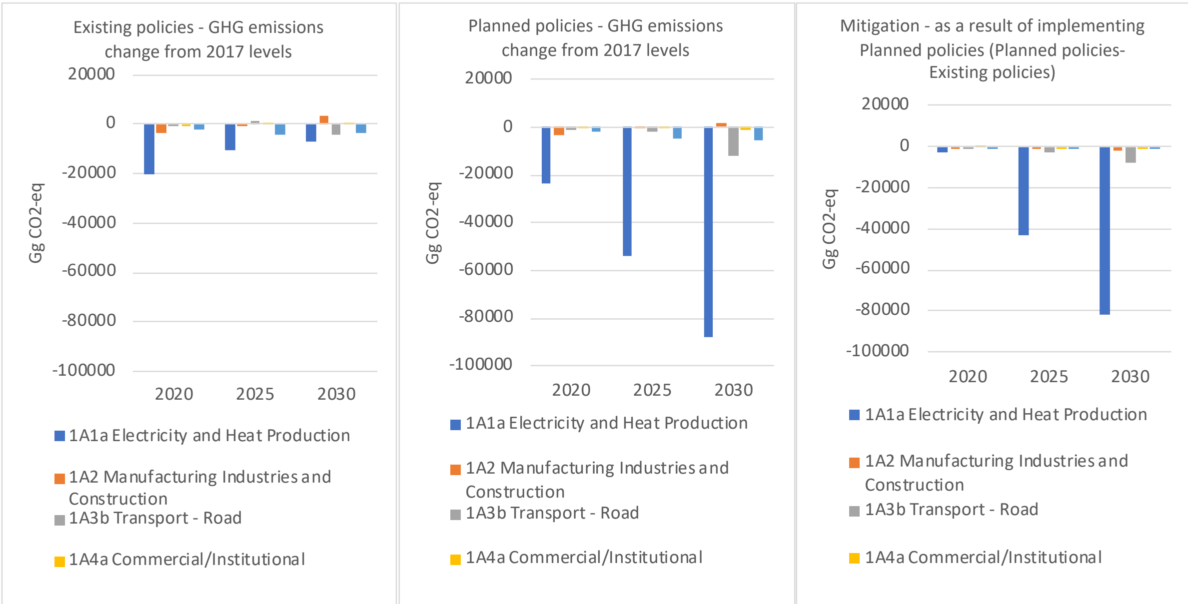

Figure 15 - Change in GHG emissions for IPCC energy sector subcategories for the Existing policies scenario (reference growth) from 2017 levels (left), the Planned policies scenario (reference growth) from 2017 levels (middle), and the difference in GHG emissions per IPCC sector between the Existing policies and Planned policies scenarios (reference growth) (right) – i.e. the mitigation effect of the Planned policies scenario in relation to the Existing policies scenario.

Figure 14 above presents changes in GHG emissions for the Existing policies and planned policies scenarios from 2017 to 2030 (left and centre graphs), and the GHG mitigation impacts of the Planned policies scenario (i.e. the difference between the Existing and Planned policies scenarios). GHG emissions changes from 2017 are, apart from a step change in land sector emissions of around 15 Mt, mainly in the energy sector. The impact of the additional policies and measures on GHG emissions is also in the energy sector. Figure 15 above shows the same differences for energy sector subcategories. While there is a relatively small reduction in emissions from road transport, the majority of both the shifts attributable to the energy transition, and to the impact of the implementation of policies and measures, are in the electricity sector, mostly as a result of investment in low-carbon technologies in the energy sector, but also as a result of the implementation of energy efficiency measures.

Out of a total mitigation impact of 98.4 Mt in 2030 (i.e. the difference in GHG emissions between the Existing and Planned policies scenarios), 95% of this mitigation is in the energy sector, 83% of this is in the electricity supply sector and 8% in the transport sector, and 4% elsewhere in the energy sector. On the one hand this emphasises the importance of the electricity sector as the focus of mitigation efforts in the 2020s (as a result of both investment in low/zero carbon generation options and in energy efficiency) as a result of the outcome of currently planned mitigation policies and measures. It should be emphasised though that this analysis is based on the mitigation impact of currently planned policies, and does *not* assess the costs and benefits of mitigation options which could be available beyond these policies and measures.

2.2.3 Sensitivity analyses

The results of sensitivity analyses are presented in Figure 16 and Figure 17 below. These exclude sensitivity analyses for different GDP levels, which are presented above. All the sensitivity analyses below were modelled with the reference growth rate.

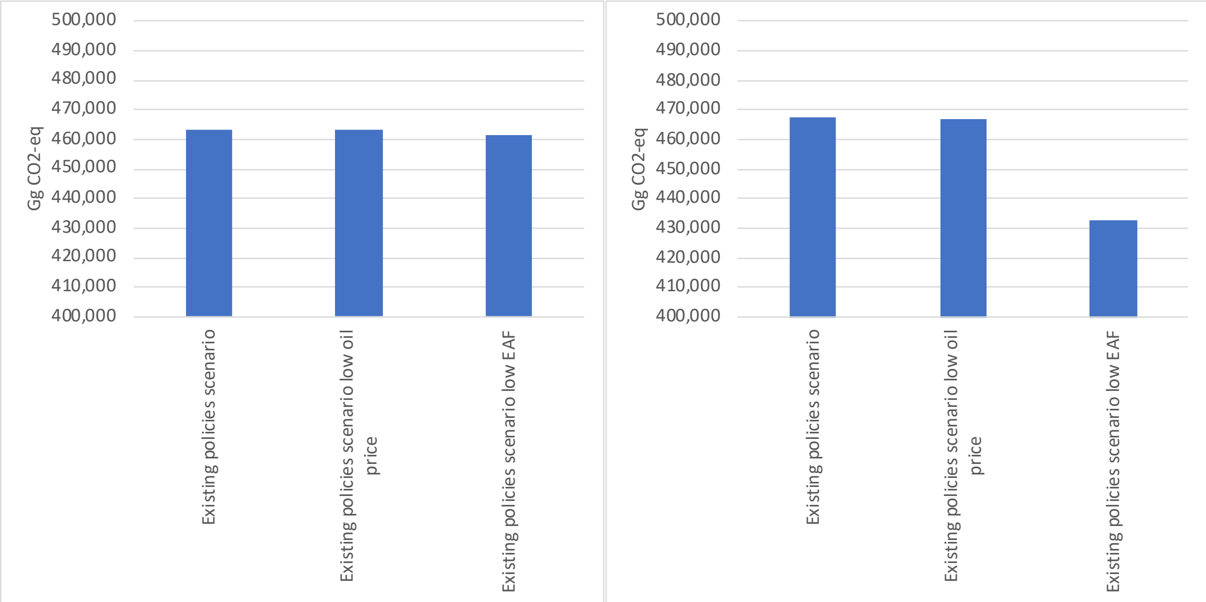

Figure 16 - Sensitivity analyses for the Existing policies scenario (reference growth) – 2025 (left) and 2030 (right)

For the Existing policies scenario, two sensitivity analyses were run. The first is with a lower oil price to test the impact on the timing of the transition away from internal combustion engines in the transport sector. The oil price follows the International Energy Agency's World Energy Outlook 2019 "Current Policies" scenario, which reaches 127 US$/bbl in 2040 follows the lower trajectory of oil price in the "Sustainable Development" scenario as a default trajectory in the modelling framework, and which remains at 60 $/bbl throughout in the sensitivity analysis (IEA 2019). As presented in Figure 16, the impact of a lower oil price is negligible, and does not drive the transition in itself (this is primarily driven by the falling costs of alternatives to the internal combustion engine). The second sensitivity analysis is to the Energy Availability Factors (EAFs) of Eskom's coal plants. The EAFs used in this analysis were those used in the IRP 2019; however, these have proved to be somewhat optimistic since 2019. A lower set of EAFs were used to test the sensitivity to these (both are contained in Table 8 above). The result of lower availability of Eskom's coal fleet is very significant to GHG emissions levels, and results in an additional drop of 35 Mt CO_2-eq, as a result of lower coal use and consequent additional investment in renewable energy technologies.

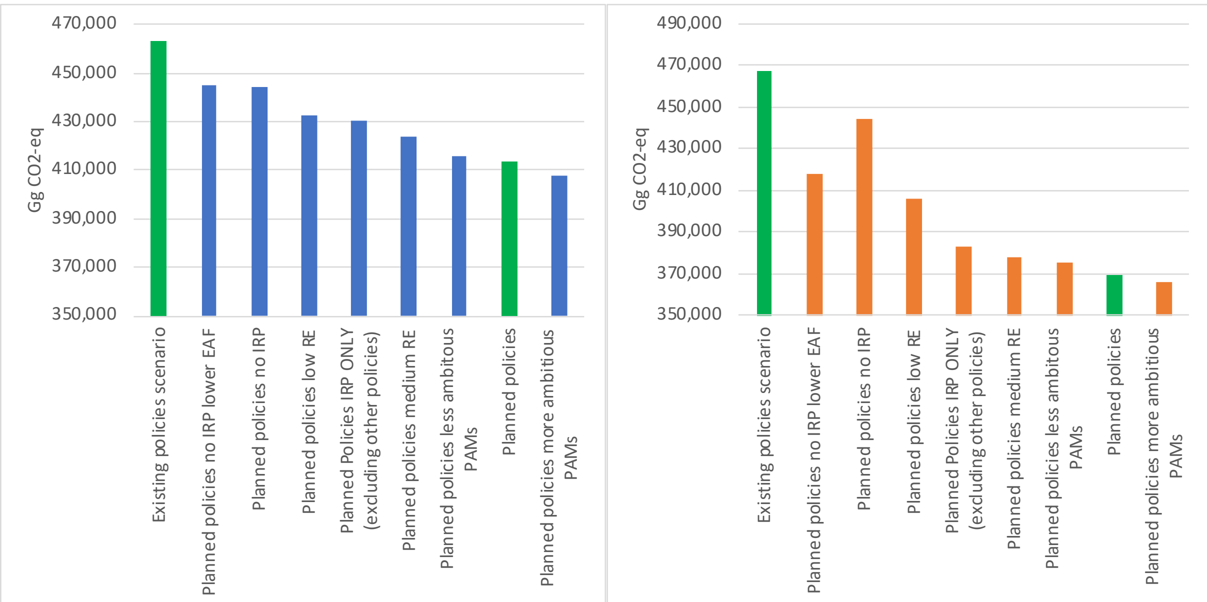

Figure 17 -Sensitivity analyses for the Planned policies scenario (reference growth) – 2025 (left) and 2030 (right)

Sensitivities were run as detailed above for the Planned policies scenario. More and less ambitious versions of the non-electricity supply PAMs, as detailed in Table 9 above, do not result in significant changes in emissions outcome. The more ambitious case resulted in additional mitigation of 3.4 Mt, whereas the less ambitious case resulted in additional emissions of around 6 Mt. Using a lower EAF for Eskom's plant, unlike in the Existing policies scenario, does not make any significant difference to emissions, since given the lower demand, the additional renewable energy which results is eclipsed by the investment in IRP 2019. This is discussed in more detail in section 2.3.1 on the electricity supply sector below, and is not shown on the above graph. As with the Existing policies' sensitivity to oil prices, the lower oil price make no significant difference to emissions in the 2020s, since the Green Transport Strategy is assumed to drive a faster transition to alternative vehicles. The details of this are considered in more detail in the section on transport below. The IRP modelled by itself, without any other mitigation PAMs, results in mitigation (compared to the Existing policies scenario) of 84 Mt as opposed to 98.4 Mt with the other PAMs as well. The other PAMs modelled by themselves without the IRP results in mitigation of 23 Mt. The reason that these do not add up (84 + 23 > 98.4) is because of the impact of energy efficiency (included in the other PAMs) which reduces the mitigation impact of the IRP (by lowering demand). The low and medium RE policies plus the other PAMS result in mitigation of 63 and 89 Mt respectively.

2.3 Sectoral GHG emissions impacts

The impacts on sectoral GHG emissions and other key indicators are considered below.

2.3.1 Electricity

The South African electricity sector is at the beginning of an energy transition from its traditional reliance on large mine-mouth coal-fired power plants, largely centred in the province of Mpumalanga, to distributed wind and solar generation plant (renewable energy or RE), supplemented by natural gas and / or a variety of storage technologies. This transition is currently being driven by the economics of generation plant, which currently heavily favour renewable energy over other potential sources of electricity. Current expectations, based on multiple studies in South Africa and elsewhere, are that the transition will be towards a mix of solar and wind, with storage / gas to balance the grid as necessary. This transition is now driven by the economics of new power sources alone, but will probably unfold faster with the added pressure to decarbonize the power system as rapidly as possible. South Africa has a legacy of large coal plants which will reach the end of their lives over the next few decades – from several plants due to retire in the next five years, to the newest plants (Medupi and Kusile), due to retire after 2050. These plants are overwhelmingly the source of GHGs in the electricity sector, with a few privately-owned on-site coal plants.

The GHG emissions trajectory in the electricity sector therefore depends mainly on the following factors:

- **Whether any further coal plants are constructed and operated in South Africa**. Currently there are no official plans for further coal plants other than the coal plants contemplated in Ministerial determinations before 2019 (Thabametsi and Khanyisa), which are very unlikely to be built, and have not been taken into account here, and the 1.5 GW of new coal capacity included in IRP 2019, which has been included in the IRP 2019 modelling here.
- **The timetable at which Eskom's coal fleet retires**. It has been assumed here that the current timetable is still the timetable included in IRP 2019. Faster retirement may lead to a faster decline in GHG emissions in the sector, depending on the capacity factors at which the remaining plants are operated.
- **The capacity factor at which Eskom's coal plants are operated**. This is probably by far the biggest factor in determining GHG emissions in the electricity sector in the 2020s, and beyond, other than the retirement of these plants. The three biggest factors which affect the capacity factor are i) the Energy Availability Factor (EAF) of Eskom's coal plants, i.e. considering planned and unplanned outages and other reliability issues, how much time each plant is available to run; ii) the electricity demand in relation to available capacity; and iii) the availability of other generation resources which are dispatched before Eskom's coal fleet. The EAF which is assumed here is the EAF used in the IRP 2019, but this has proved to be overoptimistic. The weighted average EAF used in SATIMGE, derived from Table 6 of IRP 2019, as well as the lower EAFa derived from (Wright and Calitz 2020) are presented in Figure 22 below, and contained in Table 8 above. Lower EAFs will lead to a requirement for additional capacity earlier, and will almost certainly have an impact on GHG emissions.

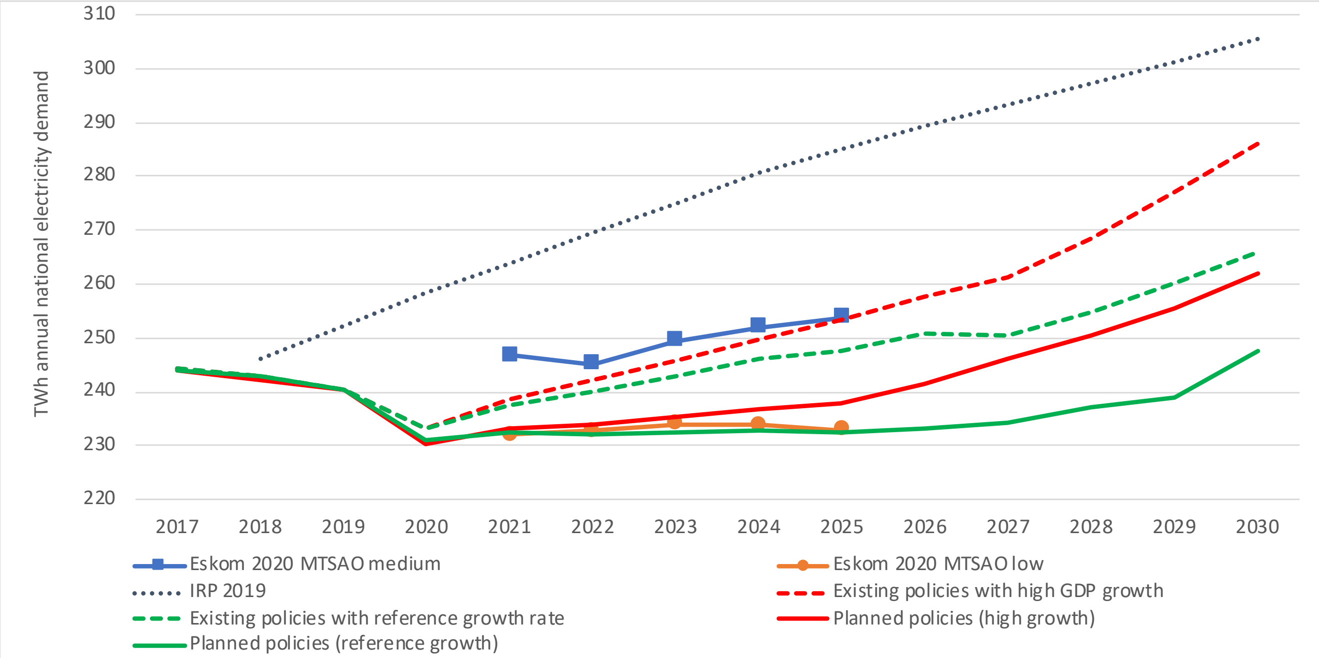

Figure 18 - Electricity demand in IRP 2019, from Eskom's 2020 Medium Term System Adequacy Outlook (MTSAO), and modelled electricity demand for the Existing policies scenario (reference and high economic growth) and Planned policies scenario (reference and high economic growth).

These will be explored in more detail below. Electricity demand is presented in Figure 18 above, for the Existing and planned policies scenarios, for reference and high economic growth, compared to the electricity demand forecast used in IRP 2019. As presented in Figure 6 above, the size of the economy, and therefore the electricity demand, is considerably smaller by 2030 than anticipated in the IRP 2019. The much higher economic growth rate assumptions are counterbalanced somewhat by the assumption in the IRP 2019 demand forecast that the electricity intensity of the economy will decline very steeply in the 2020s – by 25% compared to its 2019 value, as presented in Figure 19 below.

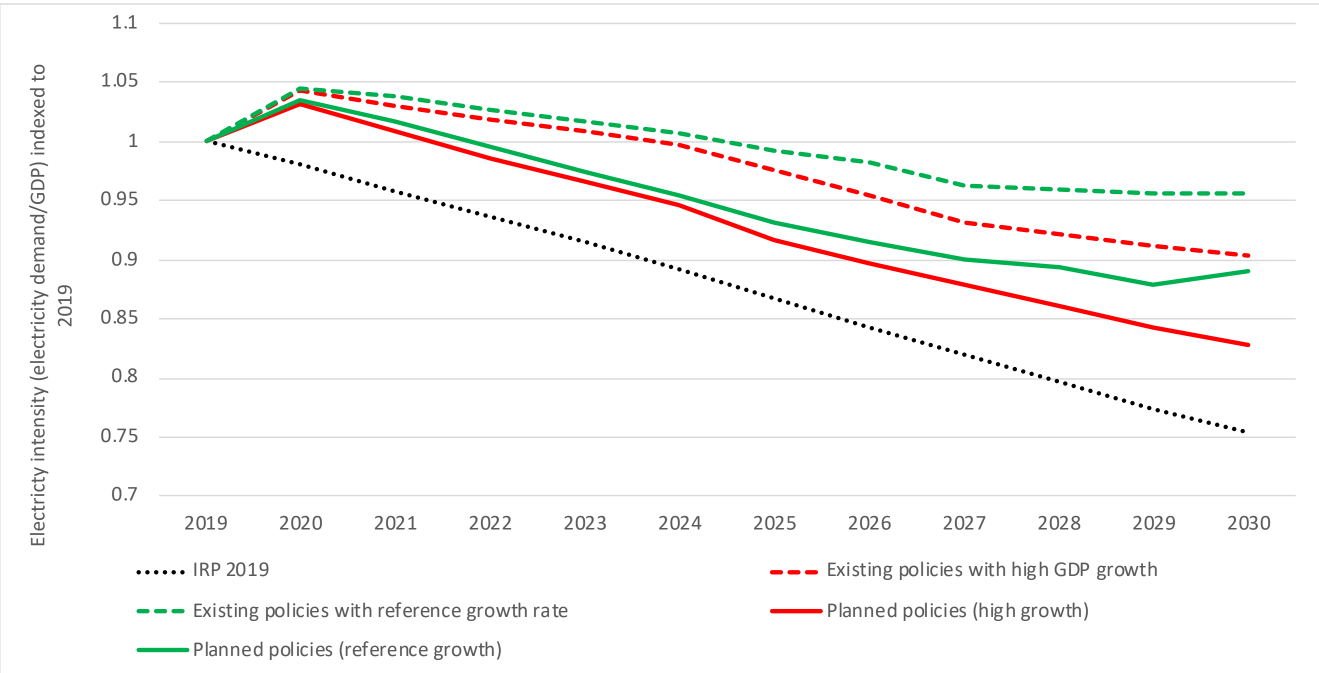

Figure 19 - Electricity intensity (electricity demand per unit of GDP) for the IRP 2019, and modelled electricity intensity for the Existing policies scenario (reference and high economic growth) and Planned policies scenario (reference and high economic growth), indexed to 2019.

By contrast, electricity intensity in the Existing and Planned policy scenarios is expected to rise significantly in 2020, since the COVID-related economic recession in 2020 did not result in a proportional drop in electricity demand (due to electricity intensive sectors being affected less by the recession than non-electricity intensive sectors such as tourism and other services sectors). The relationship between economic growth and electricity demand is expected to re-establish itself by the mid 2020s. The resultant drop in electricity intensity is not nearly as pronounced as for the IRP 2019 forecast, even with the energy efficiency improvements included in the Planned policies scenario. Short term electricity demand in the Existing and Planned policies scenarios is more in keeping with Eskom's 2020 Medium Term System Adequacy Outlook forecast. The acceleration of electricity demand in the Planned policy scenario towards the 2030s is on account of increased demand for electricity in the transport sector.

As a result, GHG emissions from the electricity sector, presented in Figure 20 below, are relatively static for the Existing policies scenario (with reference and high economic growth). These start to rise from 2023 as the economy grows larger than it was in 2019 (after the COVID recession), and more of Eskom's coal plant capacity is used. In the Planned Policy scenario, GHG emissions begin to decline in the early 2020s as planned renewable energy capacity displaces Eskom's coal plant capacity. The steeper decline from 2029 to 2030 in the Planned Policies scenario with high economic growth is caused by the displacement of Eskom's coal plant capacity by hydropower from Inga. Demand is lower with reference economic growth, and so this effect is not as apparent.

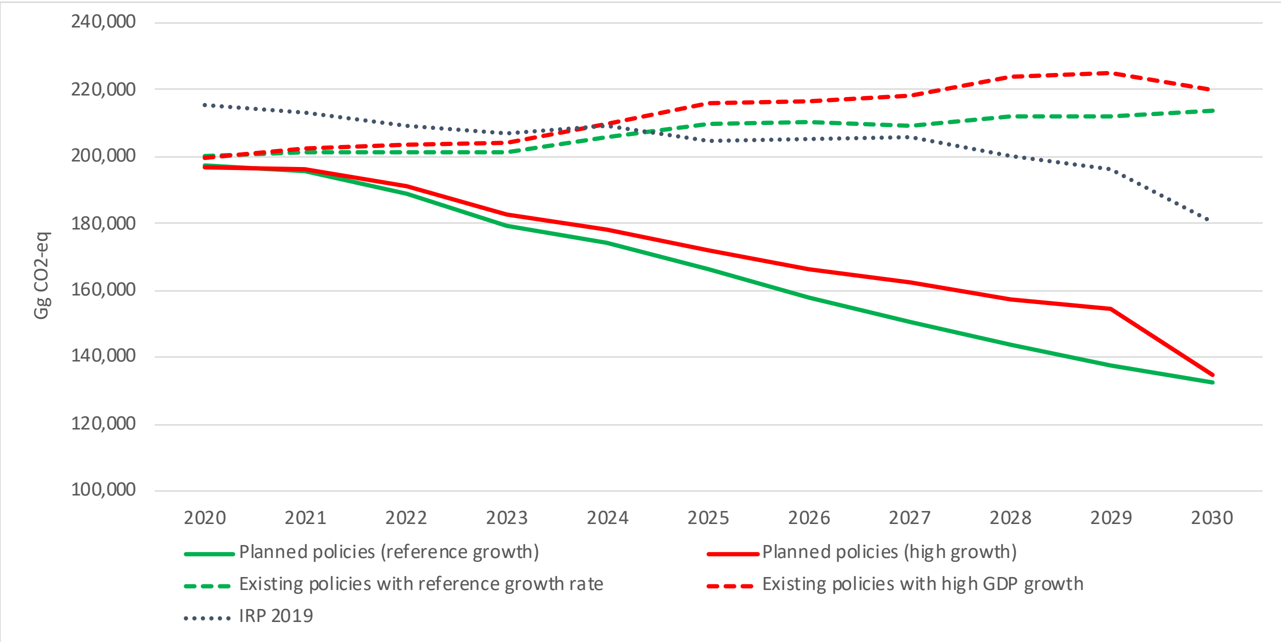

Figure 20 - GHG emissions from the electricity sector for the Existing policies and planned policies scenarios (reference and high GDP growth) compared to GHG emissions from IRP 2019.

The new capacity which is added in these scenarios is presented in Figure 21 below. Due to lower growth in electricity demand, in the Existing policies scenarios, in which capacity expansion in the electricity sector is modelled on a least-cost basis, no new capacity is required[5] other than the committed capacity contained in Table 6 above, until 2028 with a reference growth rate and a year earlier with a high growth rate.

[5] It must be emphasized here, as can be seen from the new capacity additions, that this is assuming that committed capacity begins operation as specified, and that the assumed on site solar PV in Figure 21 materializes. Moreover the SATIMGE modelling framework does not effectively model the probability of unpredictable outages of the kind that are currently leading to load-shedding in South Africa. Even though utilization rates are significantly lower than the EAF, this does not preclude the possibility of load shedding due to large proportions of capacity being unavailable at the same time. See the section below on reliability.

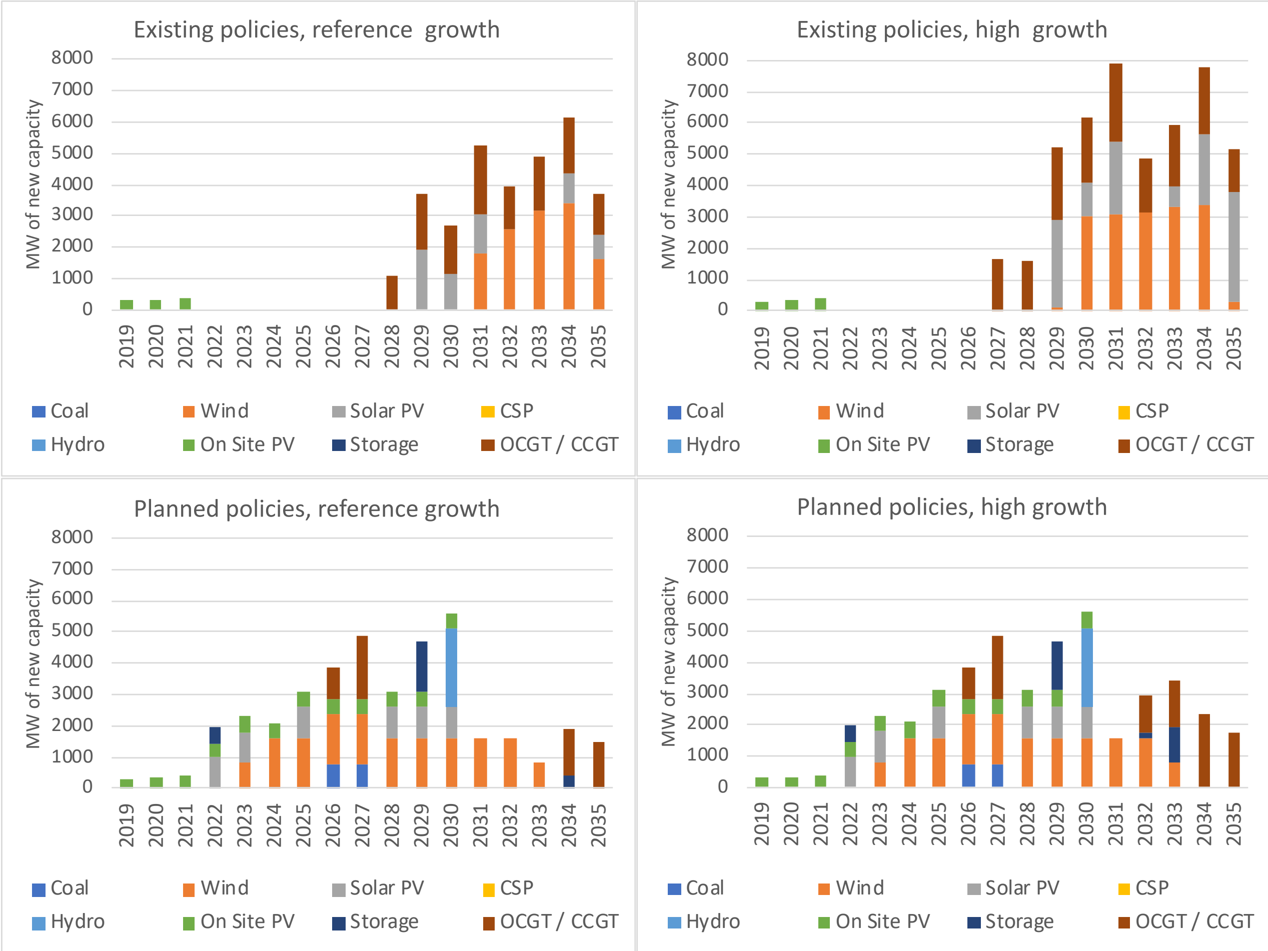

Figure 21 – New generation capacity in the Existing and Planned policies scenarios, reference and high growth

By comparison, in the Planned policies scenario, demand is lower on account of the implementation of energy efficiency programmes, and in addition, the new capacity as specified in the IRP 2019 comes online (implemented in SATIMGE as contained in Table 7 above). After 2030, apart from some deferred wind capacity from the IRP, no new investment is required other than storage and OCGT/CCGT capacity, due to what is effectively overinvestment (not considering other policy objectives such as mitigation) during the 2020s, due to lower demand.

The driver for GHG emissions is the extent to which Eskom's coal fleet is utilized, since these plants are the source of almost all of the electricity sector's GHG emissions. The utilization of the coal fleet is presented in Figure 22 below, with the projected EAFs (default and lower variant) which limit the maximum utilization rate in a specific year, and therefore the maximum GHG emissions from Eskom's coal fleet. Utilization is calculated as the modelled output of Eskom's coal fleet in a specific year divided by the maximum possible output (if all available units ran for each hour of the year). Utilization rates are low for the Existing policies scenario, until 2023, during which time slowly growing demand is met by the remaining units of Medupi and Kusile coming online; thereafter, the least-cost solution (at the assumed renewable energy and coal cost levels) is to utilize more of Eskom's existing coal capacity rather than to build new capacity, up to the level set by the EAF. The full utilization of available capacity only occurs towards the end of the 2020s with the EAFs assumed in the IRP, and before this with the lower EAFs. In the Planned policy cases, the actual utilization of Eskom's coal plants declines, as a result of lower demand due to energy efficiency, and the displacement of this capacity by new capacity in the IRP (including renewable energy, coal and imported hydro capacity).

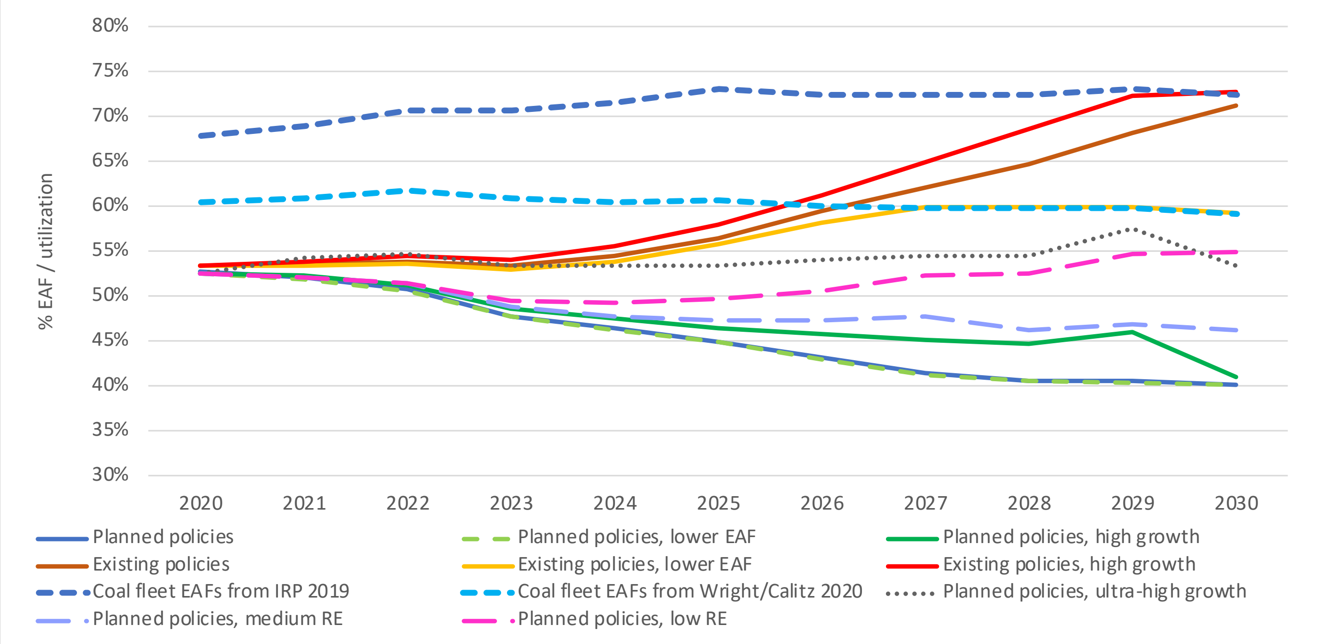

Figure 22 – Energy Availability Factors for Eskom coal plants (IRP 2019 and CSIR 2020), and capacity utilization of Eskom coal plants in Existing and Planned policies, with reference, high and ultra high growth and using different EAFs.

Even in the Planned policies scenario with ultra-high economic growth, utilization of Eskom's coal plants does not grow significantly. In the higher economic growth cases (with higher demand) new capacity from Inga causes a sharper decline in the utilization of the coal fleet. In the medium and low renewable energy plan sensitivity cases, utilization is higher, but more stable than in the other cases. The use of a lower EAF for the coal fleet makes no difference to the Planned policy cases, since utilization does not reach the lower EAF in any of the Planned policy variations.

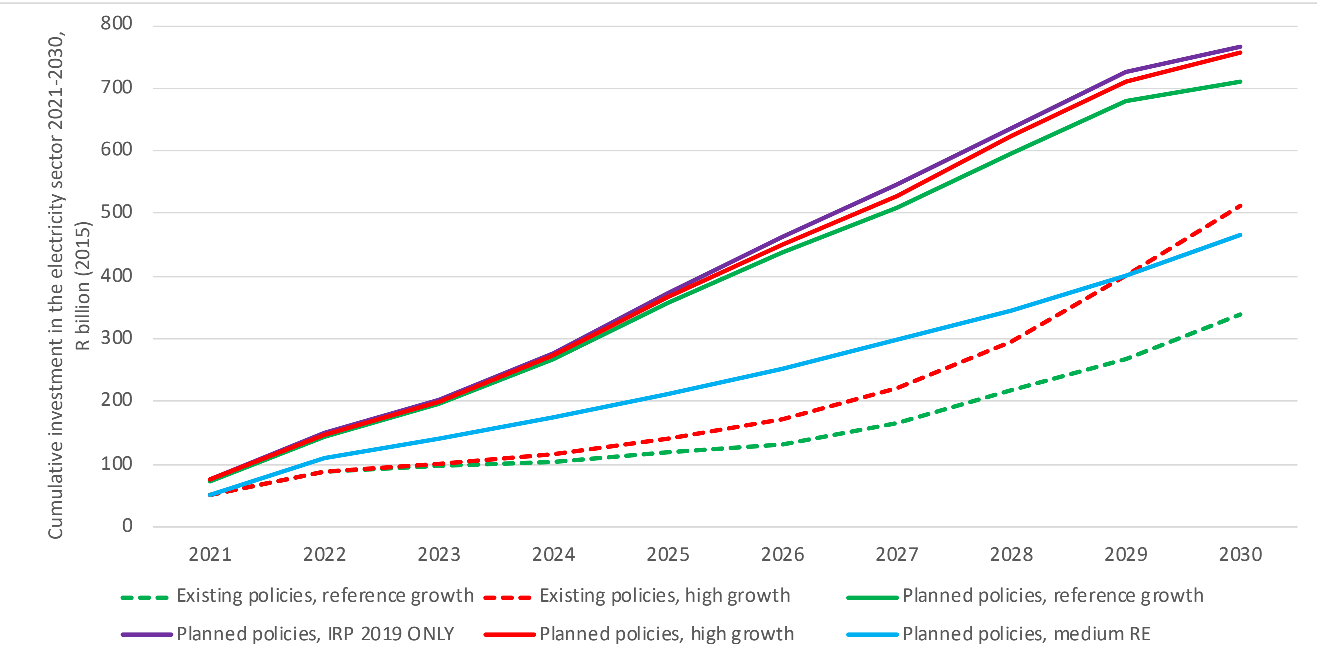

Figure 23 - Cumulative investment in the electricity sector, 2021-30, in Billions of rands (2015)

The cumulative investment requirements over the implementation periods of the NDC (2021-2025, 2026-2030) in the electricity sector are presented in Figure 23 above. These are considerably lower for the Existing policies scenario with both growth variants, and higher with no implementation of energy efficiency (i.e. implementing the IRP only). Implementation of the IRP with energy efficiency measures results in a cumulative investment of just over R700 billion. With a scaled-back RE programme, no new coal and no imported hydro, the cumulative investment requirement falls by over R200 billion, but with a lesser mitigation impact (see Figure 17 above).

The impact on electricity prices[6] is similarly varied and is presented in Figure 24 below. The price model in SATIMGE is designed to mimic the current price-setting process – i.e. that the price is based on costs (including investment costs) divided by the expected demand. This means that overinvestment in relation to actual demand will result in price increases, and measures such as energy efficiency, if accompanied by an inflexible investment programme, will result in higher prices. In the Planned policies cases, unless specified, the IRP 2019 investment schedule as described above, was forced into the model, which given the lower demand, leads to overinvestment and higher prices.

In the Existing policies scenario (reference and high growth) the price begins to rise as new capacity is needed only after 2025. Given that this is based on the unrealistically optimistic EAF in the IRP, this is likely to be too conservative. The impact of lowering the EAF is explored for the Existing policies scenario in Figure 24 – since more investment is required earlier, the price path has a slightly higher trajectory. The Planned policies scenario without the IRP is initially more expensive (since demand is lower), but later has a cheaper electricity price due to less demand for new capacity. The Planned policies scenario with the medium RE build programme results in a higher price rise as a result of new capacity being built ahead of demand, but the striking impact on the electricity price is in the variants of the Planned policies scenario which include the full IRP 2019 build plan. The Planned policies scenario with reference and high growth have the highest electricity prices in the 2020s – less so for the high growth case since demand matches supply better. The Planned policies scenario with the IRP 2019 only (i.e. no other policies and measures) has an initially lower electricity price, but from 2030 on, the price is much higher as more capacity is required without energy efficiency. The declines in the electricity price after 2030 in the Planned policies scenario are as a result of lower investment after 2030 (after overinvesting in the 2020s). The medium RE case is notable partly because it contains less wind power investment (1900 MW) and more PV (500 MW), but mostly because it excludes the new coal plants and the imported hydroelectricity from Inga. These factors together make a very significant difference to the electricity price, and to the total investment requirements of the sector to 2030 (as above in Figure 23). The impact on the overall economy will be discussed in section 2.3.9 below.

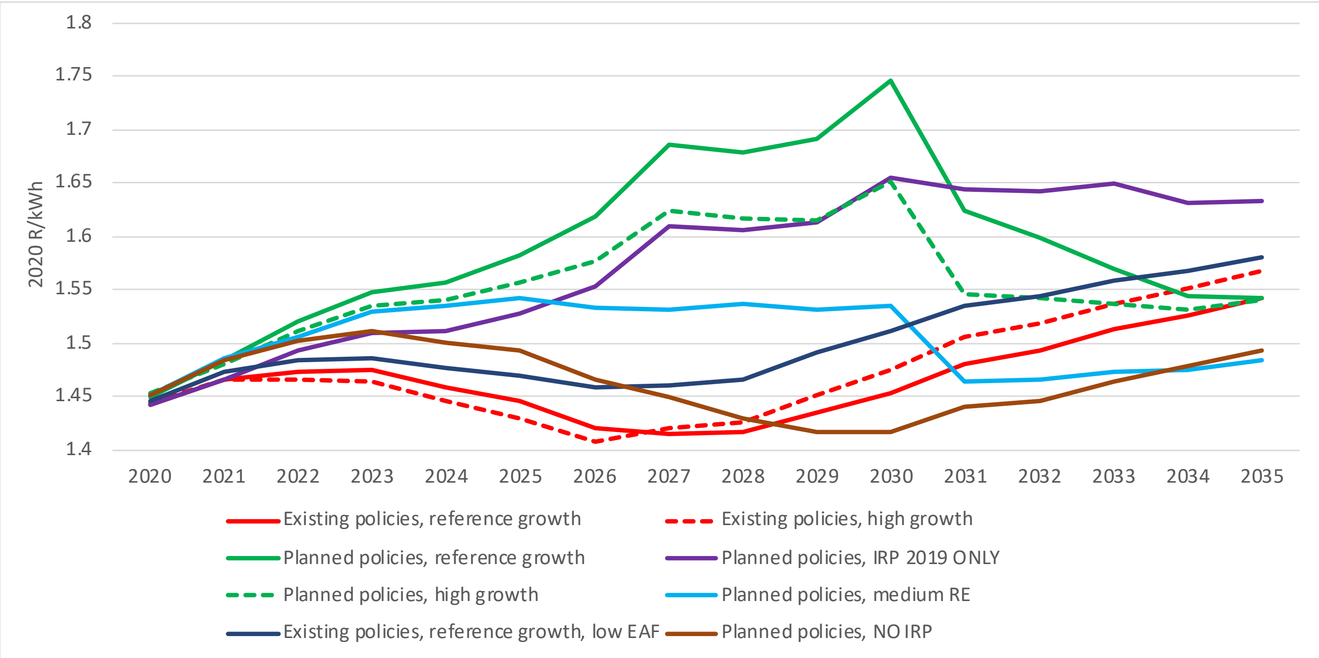

Figure 24 - Projected electricity price, in 2020 Rands per kWh

[6] Electricity prices are modelled using the projected costs of producing electricity (including generation, transmission and distribution) and the rules applicable in the current regulatory system.

2.3.1.1 A note on reliability

On the question of reliability – SATIMGE has high sectoral and end-use detail, i.e. multiple end-uses per sector (e.g. heating, cooling etc.) and multiple sectors (a similar level to DMRE energy balances) covering all energy commodities (not just electricity), and optimises over many years. To achieve this high level of sectoral/end-use/commodity detail, the temporal resolution is quite coarse (two seasonal average days are represented). To address this potential shortcoming, the results of SATIMGE are tested using the IRENA FlexTool which is run at very high temporal resolution (hourly for a full year) and the results of this process fed back as constraints into SATIMGE until no flexibility or adequacy issues remain. Constraints imposed include the reserve margin (15% firm capacity), and a constraint on the share of production to come from flexible dispatchable generators as a function of total wind and solar PV production. The electricity sector results of SATIMGE have therefore been validated using the IRENA FlexTool[7] framework for future scenarios with high proportions of variable renewable energy generation such as wind and solar PV. The basic process followed in this analysis is presented in Figure 25 below and described below.

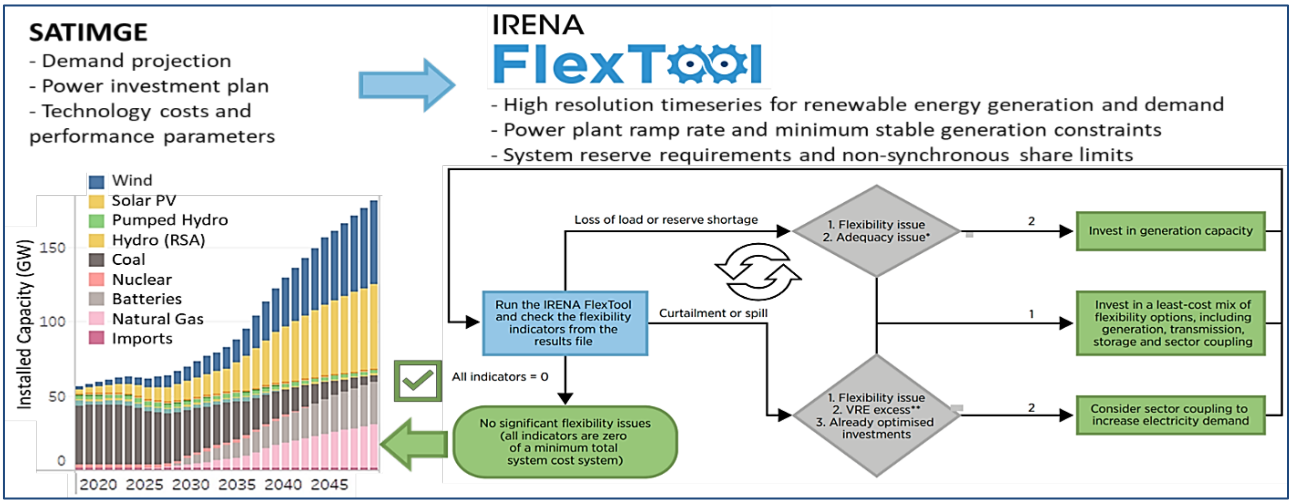

Figure 25 - Model linking and process diagram showing the combination and data flow between SATIMGE and the IRENA FlexTool flexibility and adequacy assessment tool. (Sources: SATIMGE and adaptations from IRENA FlexTool)

The inputs provided from SATIMGE to the FlexTool are: (1) the total electricity demand projection; (2) the capacities of the optimised future power plant investment plan, and (3) the cost and performance parameters for each generation technology. Additional inputs for the FlexTool include: (1) hourly renewable energy generation profiles for wind, solar, and hydro power and a future national electricity demand profile; (2) flexibility limitations for power plants such as ramp rates and minimum stable generation limits; and (3) system reserve requirements needed for every hour (15% of peak demand), and (4) limitations on the maximum non-synchronous share of generation (i.e. from wind and solar PV).

The main flexibility indicators tested with the FlexTool (among others) where: **Loss of load or unserved energy** (whenever the tested system cannot meet the full demand), **reserve shortages** (if there are any periods when there is not enough backup capacity available for unexpected plant breakdowns), **curtailed renewable energy** (when renewable generation is greater than demand and all storage is full and is therefore wasted).

Full hourly operational timeseries are provided by the tool and demonstrated below in Figure 26. The scenario depicted below is of a system in 2050 with 82.9% variable renewable generation with the remainder provided by coal and flexible gas turbines. The system is allowed to reach 100% "non-synchronous" generation, with the synchronous inertia assumed to be provided by the backup gas turbines running in "synchronous condenser mode" and additional fast frequency response provided by batteries.

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[7] The IRENA FlexTool is available at: https://www.irena.org/publications/2018/Nov/Power-system-flexibility-for-the-energy-transition . It has been used by several countries for power system flexibility assessments, is freely available and open-source, transparently and well documented, and is updated periodically with additional features. We would also like to thank IRENA for the very helpful technical support they provided on the use of the flextool.

The SATIMGE scenarios tested showed no unserved energy and no reserve shortages, while a maximum of 5.1% renewable energy curtailment was observed which is considered minimal and does not impact system reliability. An additional parameter is fed back to SATIMGE for the observed flexible generation requirements (gas in this case) which fills low RE generation periods implemented as a minimum gas utilisation constraint to ensure enough flexible backup capacity is available in the lower resolution optimisation. The combined validation of the two models show that the assumptions included in SATIMGE produce results that have sufficient system adequacy and flexibility even for scenarios with very high penetrations of variable RE.

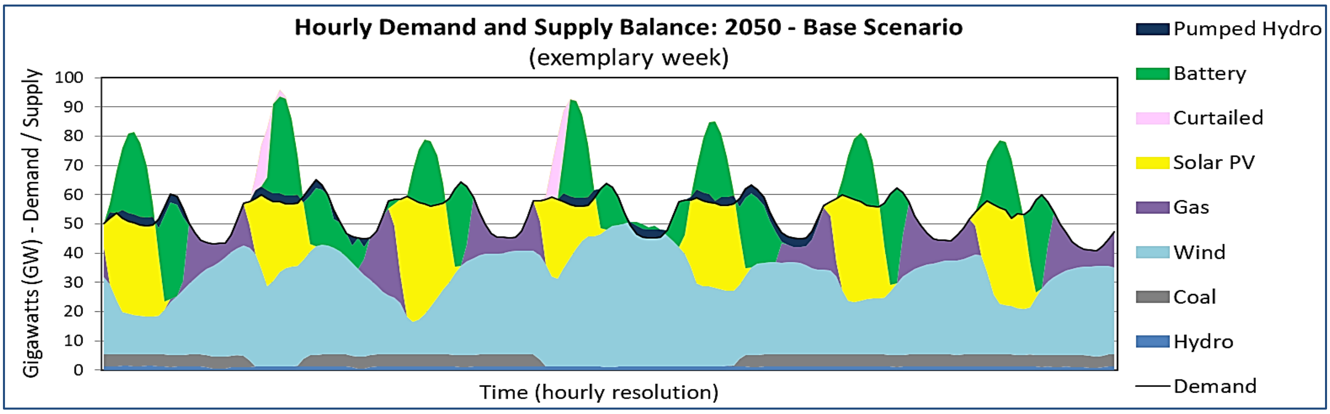

Figure 26 - Hourly electricity demand and generation profile output from the FlexTool of an exemplary week in 2050 (full year is modelled)

2.3.2 Liquid fuels

Liquid fuels infrastructure in South Africa currently consists of four crude oil refineries, one coal-to-liquids plant (Secunda) and one gas-to-liquids plant. The assumption made in this analysis is that all these plants will continue to exist until 2050 (although not all of them continue to produce liquid fuels, depending on demand) except the gas-to-liquids plant, which is assumed to shut down in 2024. In addition, after consultation with DFFE, the proposed new 400 000 bpd Aramco refinery planned for Richards Bay (due to come online from 2028) was included in the model (for all scenarios). There now appears to be some doubt as to whether this refinery will be built.

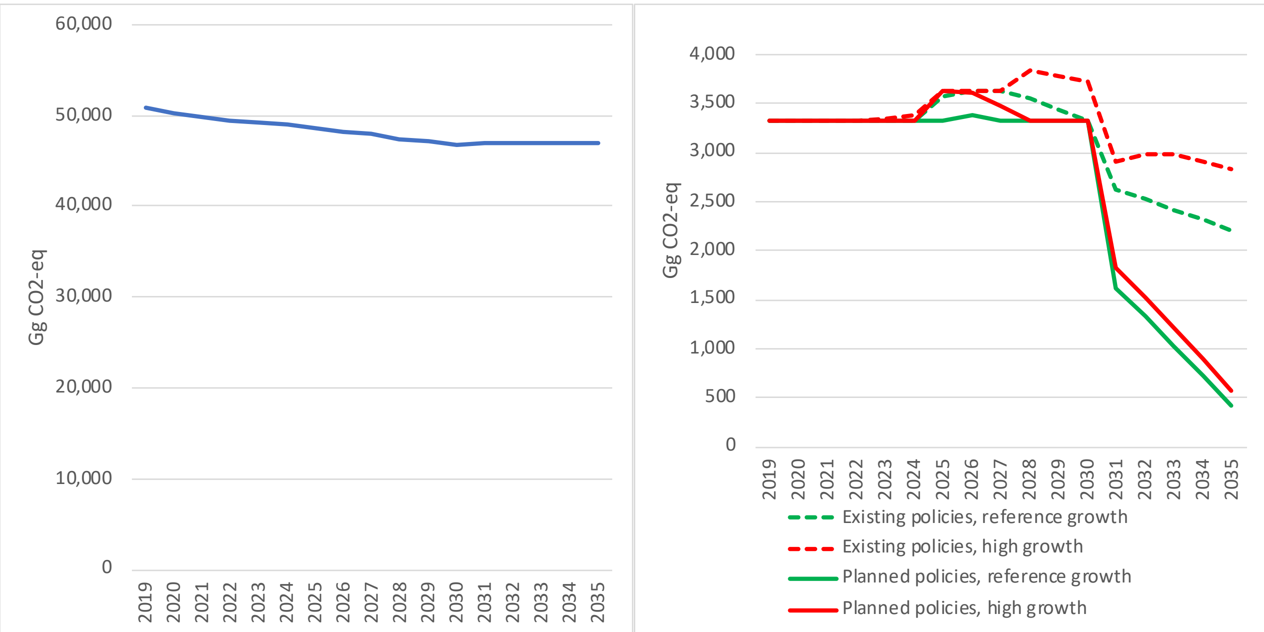

Figure 27 - GHG emissions from the liquid fuels sector. Left, emissions from coal-to-liquids and gas-to-liquids plants (identical for all scenarios), and right, emissions from crude oil refineries.

GHG emissions from liquid fuels production in South Africa are overwhelmingly from the synthetic fuels process (around 95% in 2017). There are no specific sectoral policies or measures which currently target emissions in this sector other than generic measures such as energy efficiency, the carbon tax and the carbon budgets system.

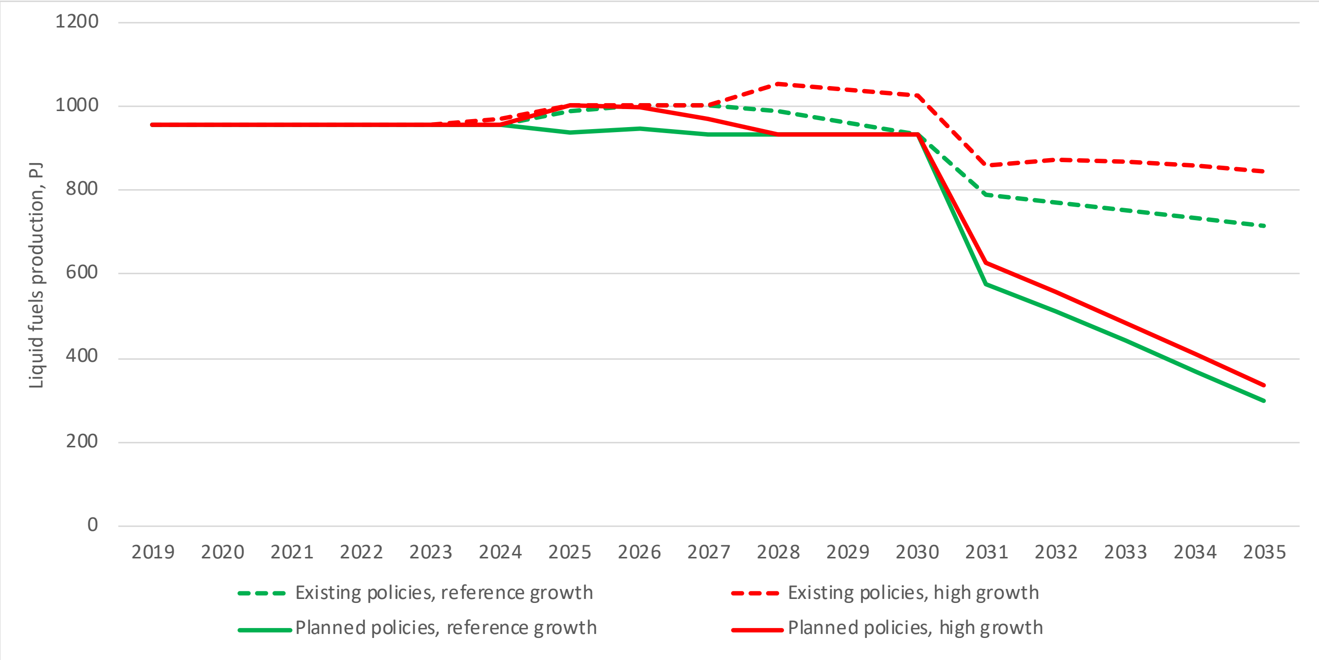

Figure 28 -Liquid fuels production in South African crude refineries and synthetic fuels plants for the Existing and Planned policies scenarios.

Emissions reduction in the sector will therefore come mainly from changes in the level of output for liquid fuels as a result of the energy transition in the transport sector (from internal combustion engines to other technologies). In addition, Sasol, the owner and operator of the Secunda facility, has announced an intention to reduce GHG emissions at their South African operations by 10% by 2030 (Sasol Ltd 2020), mainly in the provision of onsite power[8]. It has been assumed that onsite generation from coal at Secunda will be replaced by 2030 with power from the national grid, which on the margin would be renewable energy[9]. GHG emissions from both refining and synthetic fuels production are presented in Figure 27 above. GHG emissions from synthetic fuels decline slightly to 2030 as described below. Emissions from crude refineries grow slightly in the Existing policies scenarios (by less than 1 Mt), and then decline steeply after 2030 as demand drops due to the energy transition in the transport sector. This is described in more detail in section 2.3.4 below.

There is no significant change to emissions from liquid fuels production up to 2030 (other than the assumed reduction of 10% of CTL emissions). The driver for this change in emissions after 2030 is primarily the change in demand for liquid fuels, and the consequent change in output of South African refineries. Refineries are modelled with minimum utilization rates very close to their current utilization rates, and after the new refinery comes online, decline in demand leads to the older refineries ceasing production. South Africa's gas-to-liquids plant is assumed to retire in 2024, and the output of the coal-to-liquids plant is unaffected by the drop in demand, since this is the lowest-cost source of liquid fuels in South Africa. In the Planned policies scenario, the new refinery ceases production by 2035 due to lack of demand.

2.3.3 Coal supply

Coal combustion is the main driver of GHG emissions in South Africa, and reduction in coal use is also the key source of mitigation in this study up to 2030, via reduction in demand for coal-fired electricity. Total coal use in tons is presented in Figure 29 below. Coal use in 2019 is estimated to be around 176 Mt, which declines by

[8] Sasol have provided a detailed roadmap in their 2020 climate change report (Sasol Ltd 2020)for the achievement of this target, which includes other measures in addition to diversifying their electricity supply. The way this has currently been implemented in SATIMGE does not take into account the diversity of measures outlined in the report.

[9] This amounts to 4Mt or so by 2030, and it is assumed that some of the additional power in the "other" category" in the IRP replaces the coal-based onsite generation. This is not a huge reduction in terms of GHG emissions for the liquid fuels sector as a whole, but on the other hand is equivalent to the GHG emissions of ALL crude refineries in the country.

between 21% and 23% by 2030 as a result of the use of less coal power in the IRP 2019, in the Planned policies scenario. Coal use in the Existing policies scenario increases slightly to 2030, by 1-3%. Taking export coal into account (assumed to remain constant at 75 Mt during the period), this implies that total coal production in South Africa would be 1-2% higher in 2030 than in 2019 in the Existing policies scenario, and 15-16% lower in 2030 than in 2019 in the Planned policies scenario. The recovery in coal production

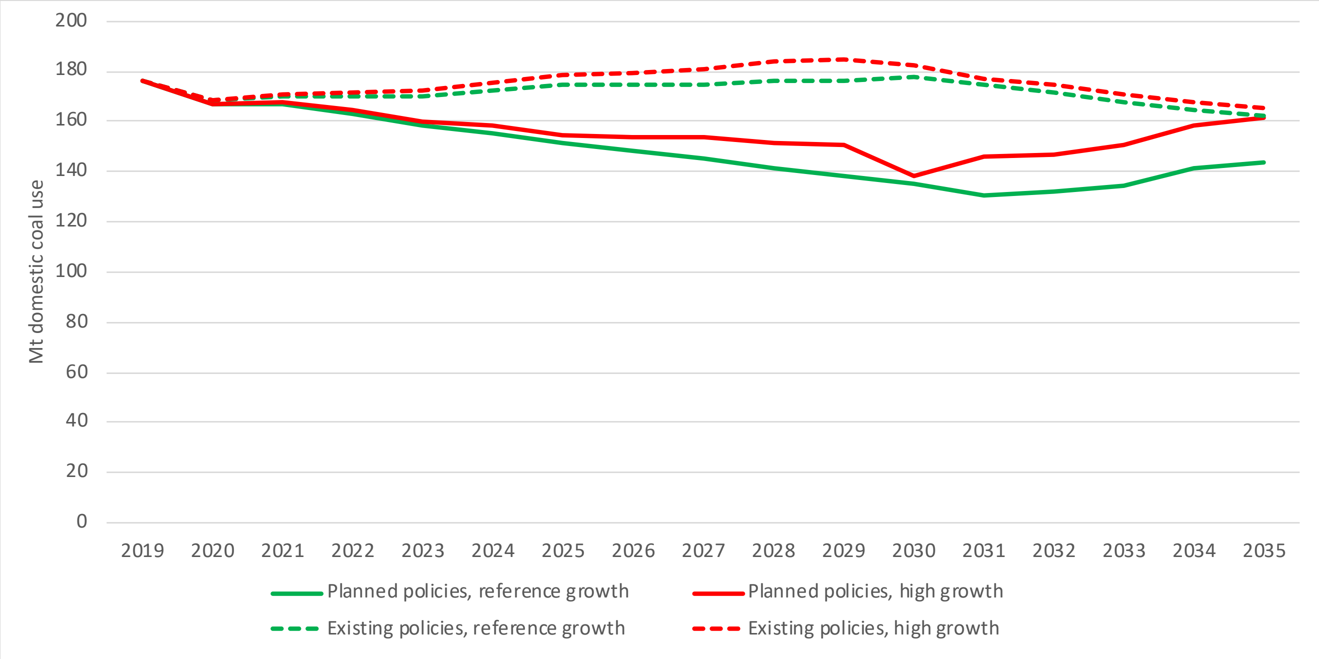

Figure 29 -Coal use in tons for the Existing and Planned policies scenarios.

2.3.4 Transport

GHG emissions from the transport sector are presented in Figure 30 below as a result of the combustion of liquid fuels, primarily in internal combustion engines. Before 2028, 95% of emissions in the transport sector are from road transport. Overall mitigation impact is less than 10 Mt (6.7 Mt for the reference growth rate and 8 Mt for the high growth rate) but still substantial.

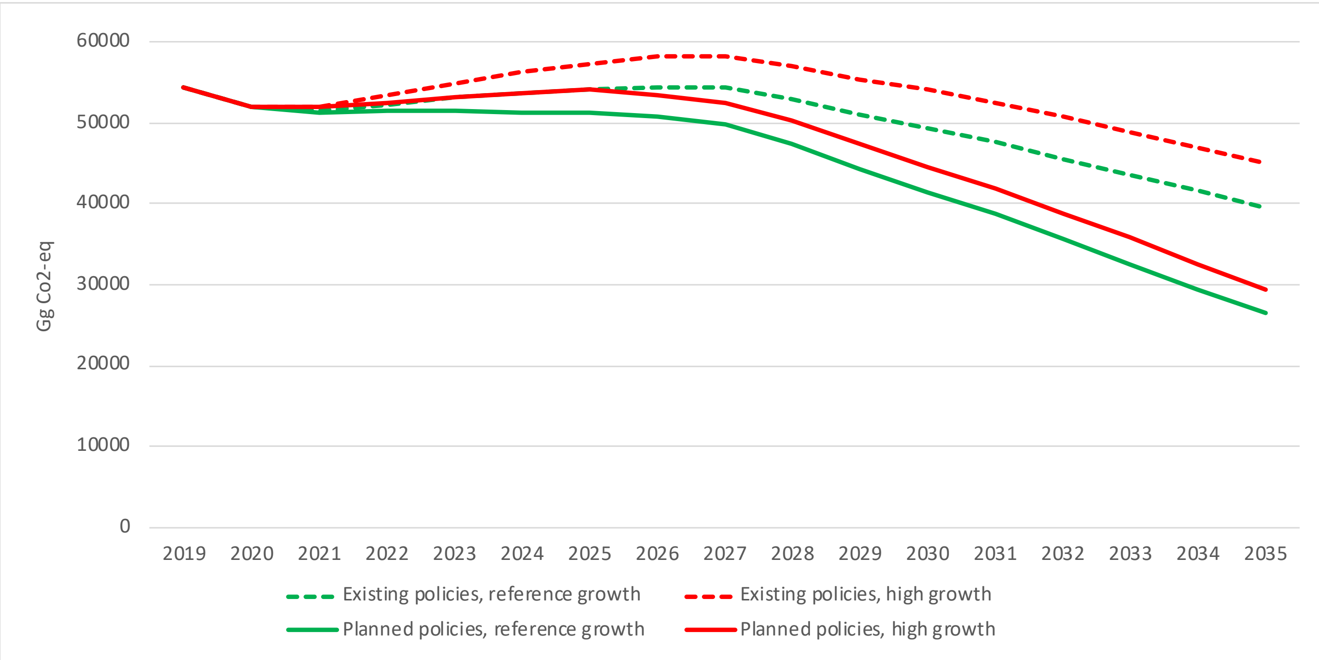

Figure 30 - GHG emissions in the transport sector in the Existing and Planned policies scenarios

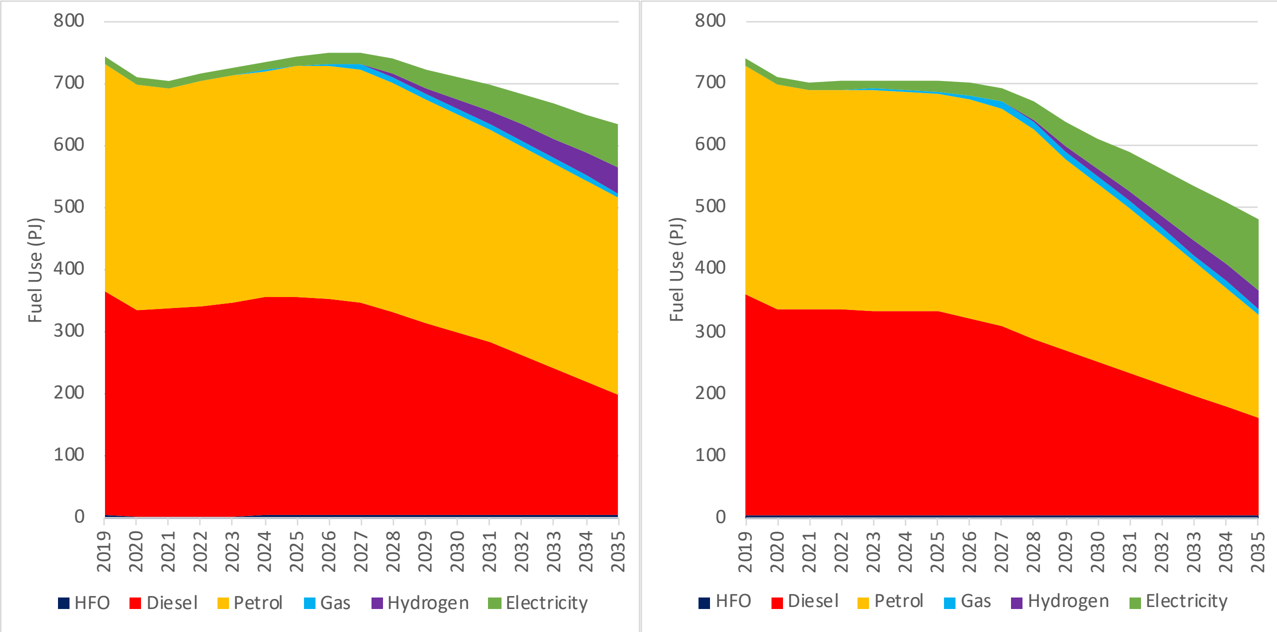

Figure 31 - Fuel use in the transport sector in the Existing and Planned Policies scenario (reference growth rate).

The decline in liquid fuels use in the transport sector is as a result of both the underlying energy transition (as a result of the changing economics of transport technologies), in the Existing policies scenario, and the additional impact of the Green Transport Strategy in the Planned policies scenario. The decline in overall fuel use in the transport sector presented in Figure 31 above is due to the shift to electricity (which does not contain the thermal losses which result from the use of liquid fuels in internal combustion engines), as well as efficiency gains from modal shifts in the Planned policies scenario. There is a marginal mitigation impact as a result of biofuels blending.

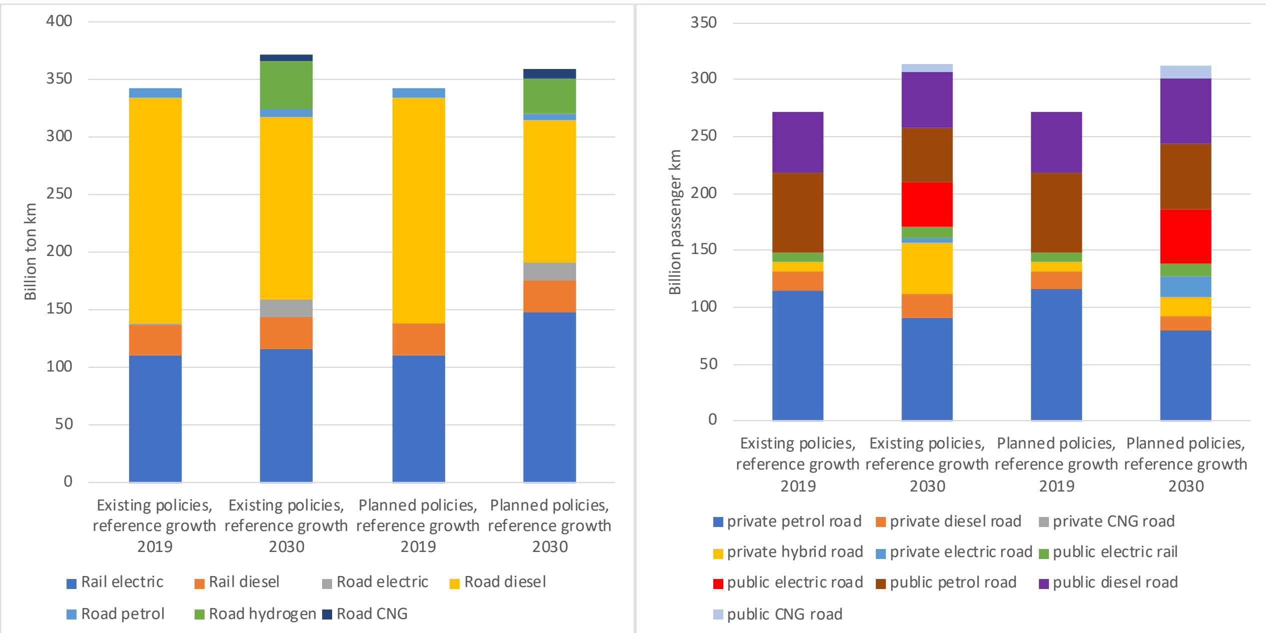

Figure 32 - Ton-kms and passenger-kms per vehicle type, fuel and mode for the Existing and Planned policies scenarios for 2019 and 2030

Total transport demand, as well as the technology used to meet the demand, is presented in Figure 32 above, for the Existing and Planned policies scenarios. In freight transport, there is a modal shift to rail (which is assumed to be mostly electrified) as specified in the GTS, in the Planned policies scenario, and a corresponding decline in the share of diesel trucks. Uptake of hydrogen vehicles is smaller. In passenger transport, there is a modal shift to various modes of public transport in the Planned policies scenario, a decline in petrol and diesel vehicles and higher uptake of electric vehicles in both public and private transport as a result of the GTS.

2.3.5 Industry (combustion and IPPU emissions)

GHG emissions as a result of fuel combustion (mainly coal for process heat) are presented in Figure 33 below. Mitigation in the Planned policies scenario is a result of energy efficiency. Further emissions reductions result from a lower economic growth rate in the Planned policies scenario, as a result of the impact of overinvestment in the electricity sector. The marginal impact on IPPU emissions is also a result of a lower economic growth rate (see section 2.3.9 below).

Figure 33 - GHG emissions in the industry sector (energy emissions) in the Existing policies and Planned policies scenarios.

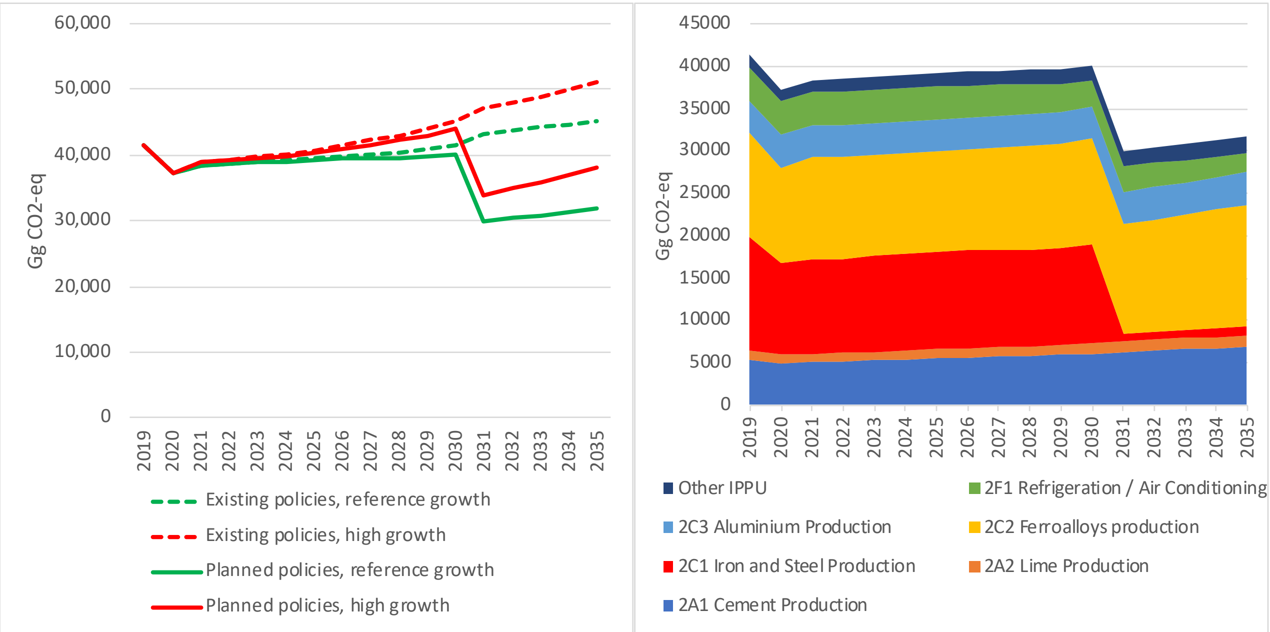

Figure 34 -GHG emissions from Industrial Processes and Product Use (IPPU) for the Existing and Planned policies scenarios (left) and IPPU emissions by category in the Planned policies scenario (reference growth rate), right.

2.3.6 Commerce, residential and agriculture (energy)

GHG emissions in these sectors are presented in Figure 35 below. Reductions in the Planned policies scenario are as a result of the assumed implementation of energy efficiency policies. It should also be noted that GHG emissions profiles in these sectors are very different from those in the NIR, as a result of different estimations of coal use.

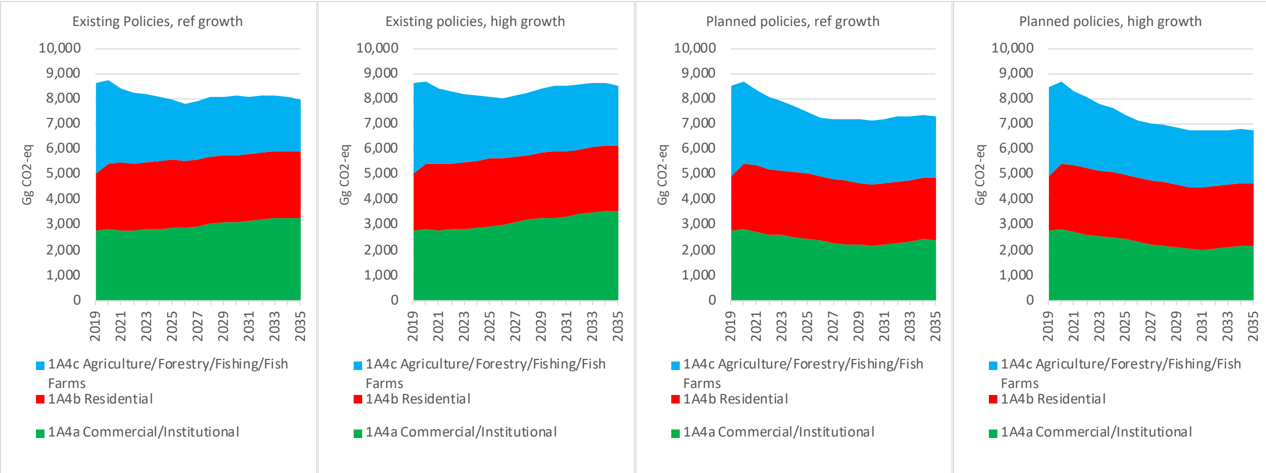

Figure 35 - GHG emissions in the commercial, residential and agricultural sectors in the Existing policies and Planned policies scenarios. Agricultural sector emissions presented here are only energy-related emissions. For other GHG emissions from the agricultural sector, see the following section.

2.3.7 Agriculture, Forestry and Other Land Use (AFOLU)

GHG emissions (non-energy) in the agriculture and land use sectors are presented in Figure 36 below. No specific mitigation policies were found for the agriculture sector, and none were modelled, and therefore the slight differences in emissions between GHG emissions for the Existing and Planned policies scenarios in this figure are as a result of slight variations in GDP (see below). Planned policies and measures as described in section 2.1.6.2 above, were modelled for the land sector, and have the impact of enhancing the carbon sink of the country by just over 2 Mt CO2-eq in 2030. This effect disappears in the years following, however. Key sources of emissions in the agriculture and land sectors are presented in Figure 37 below.

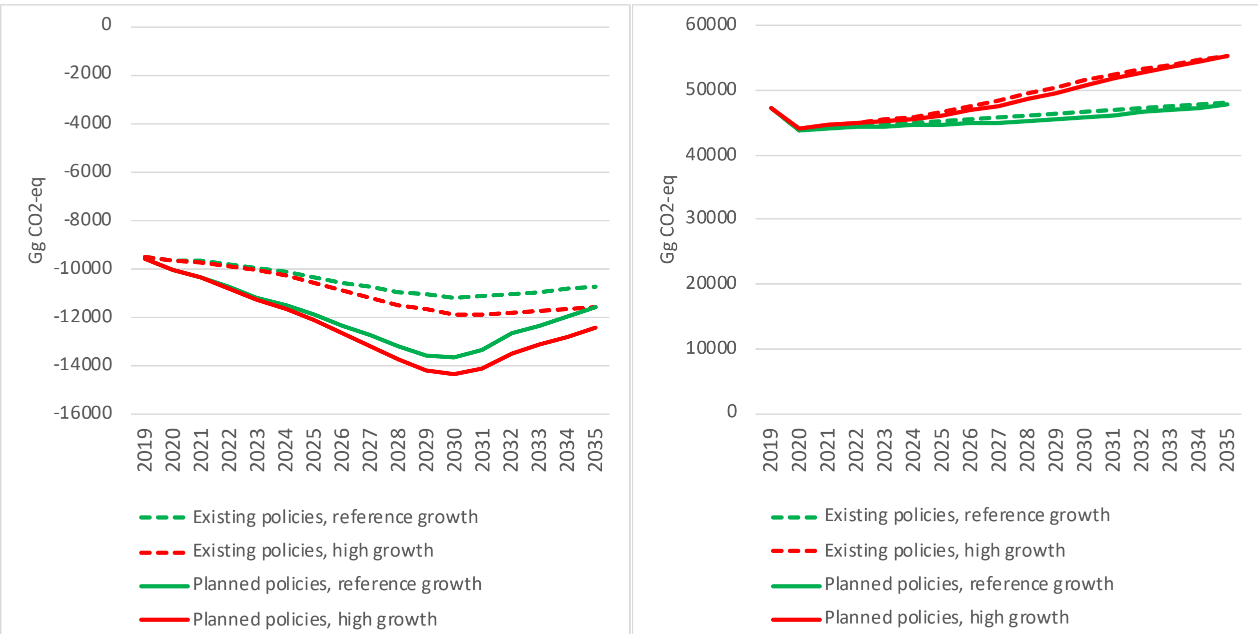

Figure 36 -GHG emissions from land use (left) and agriculture (non-energy)(right) in the Existing and Planned policies scenarios.

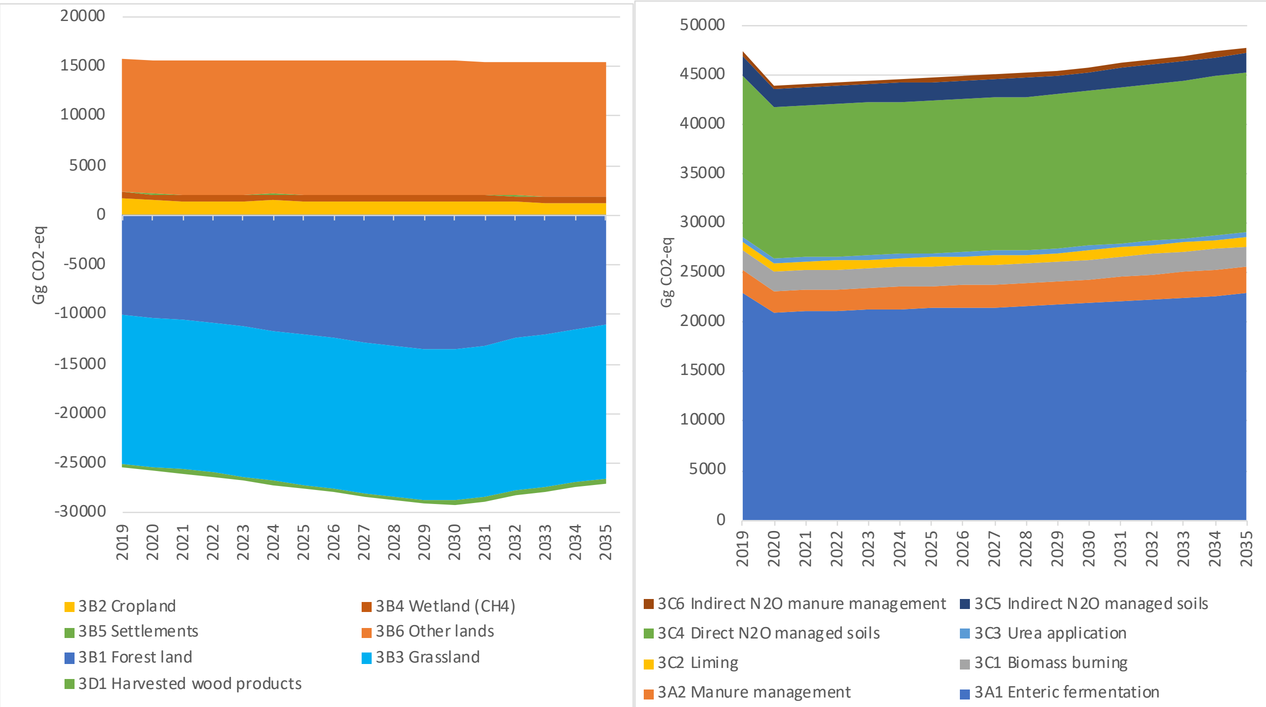

Figure 37 --GHG emissions from land use (left) and agriculture (non-energy)(right) in the Existing and Planned policies scenarios, by category.

2.3.7.1 A note on natural disturbances

As noted above, DFFE has opted not to include GHG emissions from natural disturbances in accounting for South Africa’s NDC target. The reason for this can be seen in Figure 38 below. GHG emissions from natural disturbances vary randomly, with a high degree of interannual variability, over the historical period, with an average value of 24.6 Mt CO_2-eq. These fluctuations are mainly a result of wildfires, and although these are possibly correlated with factors such as drought, are not possible to predict. From 2018 on, these have been modelled as a constant value derived from the historical average. Excluding these from accounting for the target therefore provides more policy certainty for the overall outcome of mitigation policies, but does have the effect of reducing overall GHG emissions by the value for natural disturbances emissions for the relevant years in relation to total net GHG emissions estimated in the NIR.

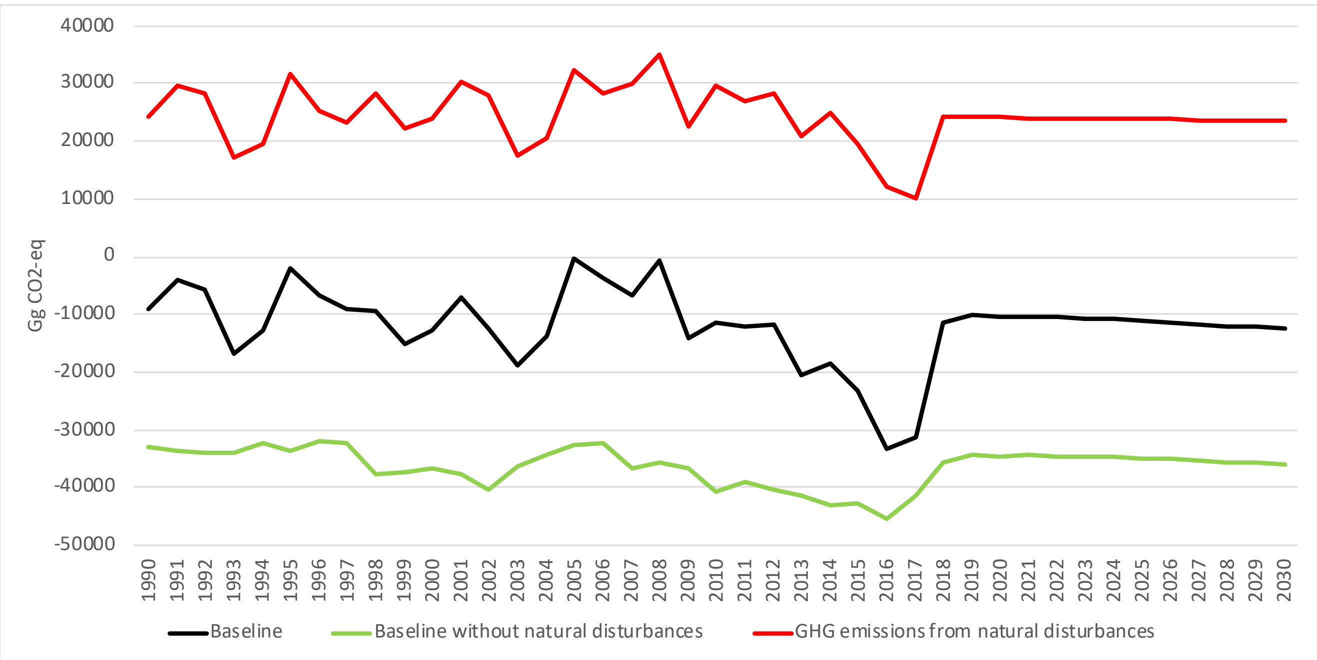

Figure 38 - Net baseline land use emissions with and without natural disturbances, and GHG emissions from natural disturbances. Data to 2017 is historical, and data from 2018 on is modelled.

2.3.8 Waste

Waste emissions, presented in Figure 39 below, decline to 2030. This is primarily as a result of earlier modernisation through the implementation of the 1st and 2nd National Waste Management Strategies (NWMS). Further improvements that should result from the implementation of the 3rd NWMS as assumed in the Planned policies scenarios, would manifest in emissions reductions only in the longer term, as a result of which there is very little difference between waste emissions in the two scenarios. The waste sector nonetheless will contribute significantly to meeting any NDC target, since GHG emissions decline by around 5 Mt between 2019 and 2030.

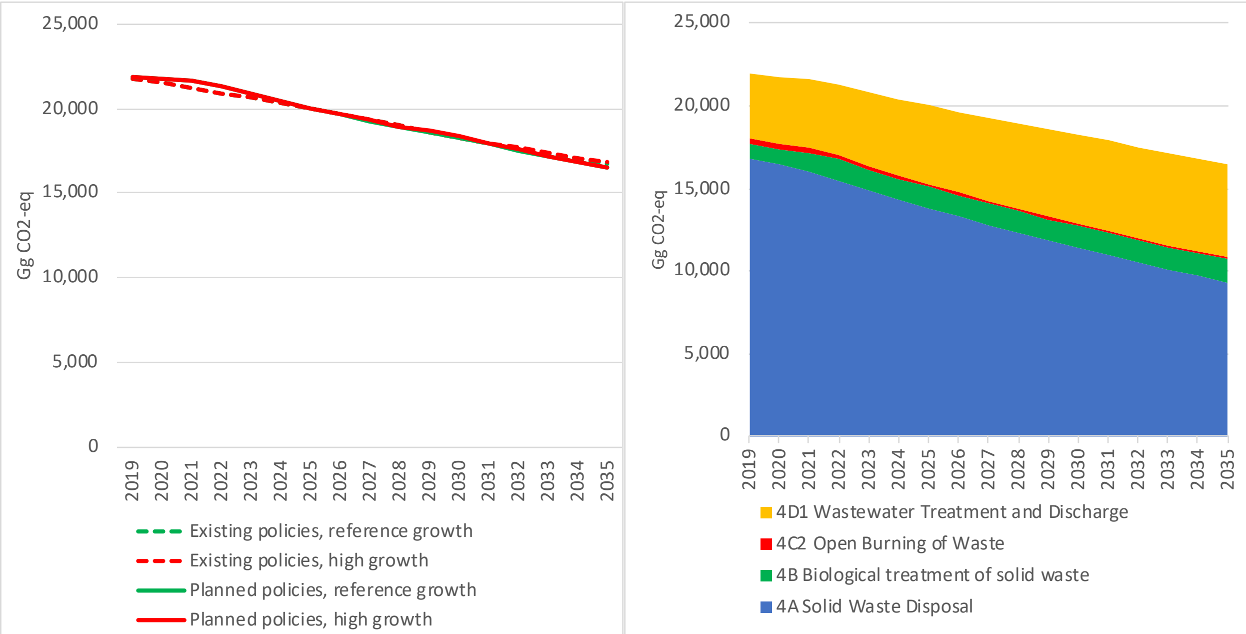

Figure 39 - GHG emissions from the waste sector in the Existing and Planned policies scenarios (left), and by category in the Planned policies, reference growth scenario (right).

2.3.9 Impacts on GDP

The SATIMGE modelling framework also includes a dynamic CGE model, which interacts with the energy-emissions model. Economic impacts of costs incurred in the energy model thus have an impact on economic growth, which in turn affects demand in the energy model. The key indicator is the overall impact on GVA, which is closely correlated to employment and other social-economic indicators. The impacts on employment are not only reflected in the relevant sectors in which investment takes place, but across the economy. Here, the impact on GVA is presented for the key scenarios and their variations in Figure 40 below, relative to two variants of the Existing policies scenario – one with the IRP 2019 EAF for Eskom's coal fleet, and the other with a lower EAF, as presented in Figure 22 above. The lower EAF case has an impact on economic growth relative to the higher EAF case due to the need for more investment in electricity generation sooner.

What is most notable though is that the inclusion of the IRP build plan as opposed to a least cost energy plan has a relative negative impact on economic growth. As the IRP plan aims to build capacity necessary for an electricity demand associated with a much higher economic growth rate than is now anticipated in the 2020s. This impact is lower relative to the lower EAF case. Energy efficiency has a positive impact on the economy when paired with a least-cost demand-responsive electricity supply investment plan (as in the Planned policies, no IRP case). When tied to a fixed investment plan resulting in overinvestment, energy efficiency exacerbates the impact on the electricity price[10]. Although this was not explored explicitly in this study, it

[10] It should be borne in mind that energy efficiency interventions, which could take the form of either systemic interventions such as energy management, or enhanced standards, or direct investment in more energy-efficiency end-use technology, are not assessed in the energy model as having a higher cost. This is on the assumption that energy efficiency programmes will have a market transformation impact and that the cost of more efficient technologies will be around the same in the medium terms. This may not be the case for much more ambitious energy efficiency programmes, where large-scale investment is required in new equipment. The potential impact on employment of energy efficiency programmes, is also not modelled in detail.

seems, by contrasting the Planned policies case to the Planned policies, no IRP + RE programme (that has more solar PV and less wind, and no coal or hydro plants), that much of this economic impact is as a result of investment in both the new coal plants and in Inga. It seems as a result of this analysis that in terms of mitigation, further work should be done to explore more optimal economic pathways for the electricity sector in the post-COVID era.

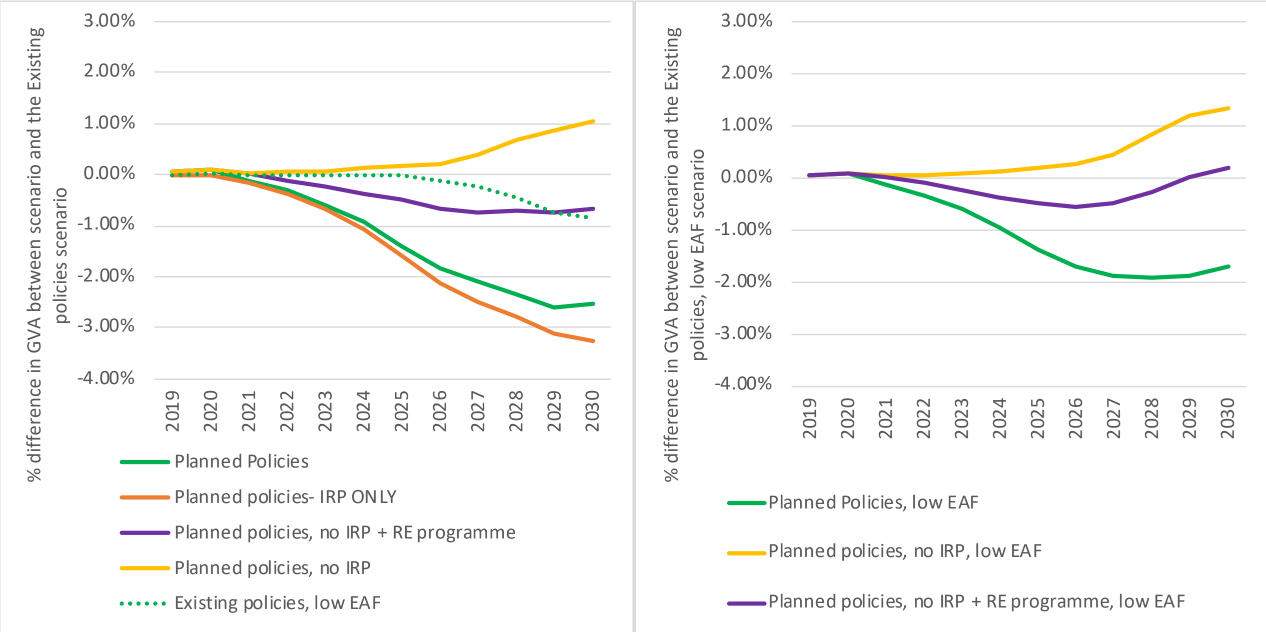

Figure 40 - Relative size of GVA of different modelled cases vs the Existing policies scenario (left) and the Existing policies scenario with a lower EAF (right).

3 Recommendations for NDC target range levels

The setting of revised NDC targets is not necessarily synonymous with the outcome of planned mitigation policies and measures, given the context of the international climate change regime. Countries may choose whether to adopt a very cautious approach to setting NDC targets (which would probably result in overachieving the target), or a more ambitious approach (which may risk not achieving the target, but may be more successful in attracting climate finance or achieving other diplomatic objectives). The target range in South Africa's NDC, an unusual form of NDC target, leads to further possibilities.

As outlined below, the central aim of this assessment is to assess the impact of planned policies and measures on South Africa's GHG emissions in 2025 and 2030, with the goal of assessing the risks and opportunities of identifying specific NDC target levels for South Africa. The extent to which these targets are aligned with GHG emissions projections (i.e. are aligned with the expected outcomes of mitigation policies and measures), will depend on the consideration of a number of key factors:

- The risks to South Africa of not meeting its NDC target. This can be assessed on the basis of this analysis to a large extent, which relates potential target levels to the impact on GHG levels of policy implementation and economic growth. It also needs to be emphasised that the Paris Agreement's legal framework for NDC targets is based on obligations of conduct rather than outcome – Parties are obliged to set targets, and to undertake and report on efforts to achieve these, but are not actually legally obliged to meet targets. There is therefore no compliance risk in setting overambitious targets. Nonetheless, not meeting NDC targets will pose a reputational risk for South Africa.
- Equity, and alignment with the Paris Agreement's long-term temperature goal. The Paris Agreement requires Parties' NDCs to contribute fairly to the achievement of the long-term temperature goal ("well below 2 degrees", with efforts to achieve 1.5 degrees). This forms the basis of the "fair share" analysis below. In addition to this, further alignment is demonstrated by the aspirational goal expressed in South Africa's Low Emissions Development Strategy communicated to the UNFCCC in

2020 to reach net zero CO_2 emissions in 2050, and would also be demonstrated by GHG emissions peaking and declining earlier than 2035.

- Trade and competitiveness / transition risk. These risks arise either from an NDC which is seen to be insufficiently ambitious, in the form of potential border tax adjustments and / or other forms of potential trade barriers, or from insufficiently ambitious climate and energy policies, associated with an unambitious target, which could leave South Africa behind in the various energy transitions taking place globally. In the latter case there could be additional risks to South African exports which depend on high-carbon infrastructure elsewhere. On the first risk, both the updated EU and United States NDCs (communicated in late 2020 and April 2021 respectively) refer to the possible imposition of border tax adjustments to protect their national economies from high-carbon imports from countries with insufficiently ambitious NDCs. The risks of South Africa lagging behind in the energy transition is a very real one, but is beyond the scope of this analysis; this would include the risk of, for instance, losing early-mover advantage in a renewable-based green hydrogen export industry.
- Ability to attract international climate finance / international climate finance. An NDC which is not ambitious and clearly aligned with the implementation of ambitious mitigation policies is not likely to be able to attract significant amounts of international climate finance, to finance both the incremental costs of ambitious mitigation policies and also the costs of the just transition.

3.1 The limitations of this study

There are three important caveats which need to be borne in mind in terms of this analysis and using it to guide the setting of NDC targets:

1. The analysis has considered to the extent possible a number of uncertainties concerning economic growth, the degree of policy implementation, and other technical factors such as the EAF of Eskom's coal fleet, and alignment with the national GHG inventory. There are other uncertainties which have not been considered, which include possibilities such as the planned coal plant in the Musina-Makhado Special Economic Zone[11] which is not contained in the IRP 2019, which would add a significant quantity of GHGs to the national total.

2. The analysis only assesses planned policies and measures, and does not extend beyond these. The premise of the study is that given that these (with the exception of the draft post-2015 National Energy Efficiency Strategy) have been consented to by Cabinet, these constitute what is politically possible in South Africa in terms of mitigation at the time at which the study commenced. The study has therefore not assessed the possibility of further mitigation possibilities (for instance, more mitigation in the electricity sector), or whether the mitigation policies and measures assessed here are necessarily the most cost-effective means to achieve specific policy objectives, including mitigation. It is important to emphasise that no further mitigation options were considered here.

3. The Existing policies scenario assumes that where there are no specific policies, global technology changes (at this stage in the electricity and transport sectors) will affect investment choices on a purely economic basis – in other words, in the electricity and transport sectors, in the absence of other guidance, least-cost investments will result. This is contrasted to the Planned policies scenario, in which the pace at which new investments are made in these sectors with new technologies is accelerated as a result of the IRP 2019 and the Green Transport Strategy. It is possible that South Africa may choose to pursue a higher-carbon and more expensive pathway which would delay these energy transitions in South Africa. This possibility has not been analysed here.

3.2 Potential target ranges given uncertainties in economic growth and implementation

Given these caveats, the technical analysis relevant to the 2025 and 2030 NDC target ranges is presented in Figure 41 below, with different economic growth rates, and ranging from no implementation of planned policies (the Existing policies scenario) to full implementation of planned policies (the Planned policies scenario). The "Likely 2025/30 emissions ranges" combine these uncertainties. It is evident from this analysis

[11] For instance, https://www.sanews.gov.za/south-africa/limpopo-sez-readies-lift .

that in both 2025 and 2030, the target ranges could be reduced considerably from their 2015 values (in the 2015 NDC).

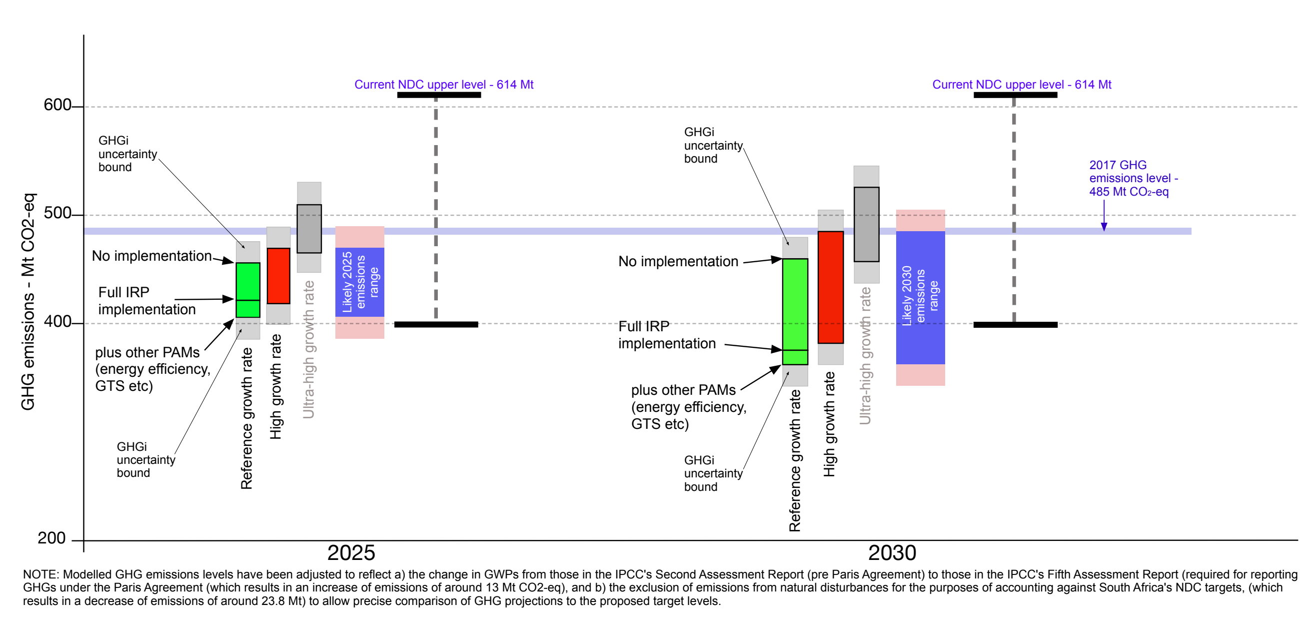

Figure 41 – Range of likely GHG emissions outcomes for the South African economy in 2025 and 2030, adjusted to take into account the change in GWP values under the Paris Agreement and the planned exclusion of natural disturbances from accounting for the NDC target. Uncertainty ranges are included to accommodate uncertainties in the estimation of GHGs in the national GHG inventory.

It is implausible in terms of the Paris Agreement’s requirement for countries to submit NDCs which represent their “highest possible ambition” (see below) to choose an NDC target which is above a least-cost emissions trajectory. There may be reasons to justify a conservative target for 2025, given the short timeframe and uncertainties about the post-COVID recovery. However in 2030, full implementation of planned policies would result in GHG emissions below the lower end of the current target range. To allow for implementation and other risks, it would seem prudent to consider moving the upper end of the target range to a value of between 420 and 450 Mt CO2-eq in terms of this analysis. A more ambitious target would be possible, below 420 Mt in 2030, with heightened risks of not meeting it. Given the change in national circumstances (including GDP growth projections) and the results from this analysis on the economic impacts of implementing the IRP 2019 as it is currently, there is a strong case to consider undertaking further analysis on cost-effective mitigation pathways which are consistent with South Africa’s development challenges.

3.3 Fair share considerations

Selection of a target level should also, in terms of the Paris Agreement, require the consideration, from an equity point of view, of what South Africa’s “fair share” of the global effort to reduce GHG emissions, taking into account the principles of the Paris Agreement of common but differentiated responsibilities, respective capabilities and national circumstances. A separate analysis was undertaken of South Africa’s legal obligations under the Paris Agreement, and also of South Africa’s “fair share” of the global emissions budget in 2030 consistent with the long-term temperature goal of the Paris Agreement (UCT 2021). The “fair shares” analysis was based on data and analysis using the Climate Action Tracker (CAT) (https://climateactiontracker.org/countries/south-africa/) and the Climate Equity Reference Calculator (https://calculator.climateequityreference.org/) (CERC). Data for both CAT and CERC was recently updated. In the case of CAT, in September 2020, and in the case of CERC, an update is forthcoming. The “fair shares” analysis was undertaken *before* these updates, and updated results are presented in Figure 42 below, which include the results from an assessment of the draft updated South African NDC undertaken by the Climate Equity Reference Framework team (who maintain CERC), which was submitted as an addendum to their written submission on the NDC by the Centre for Environmental Rights (Climate Equity Reference Project 2021).

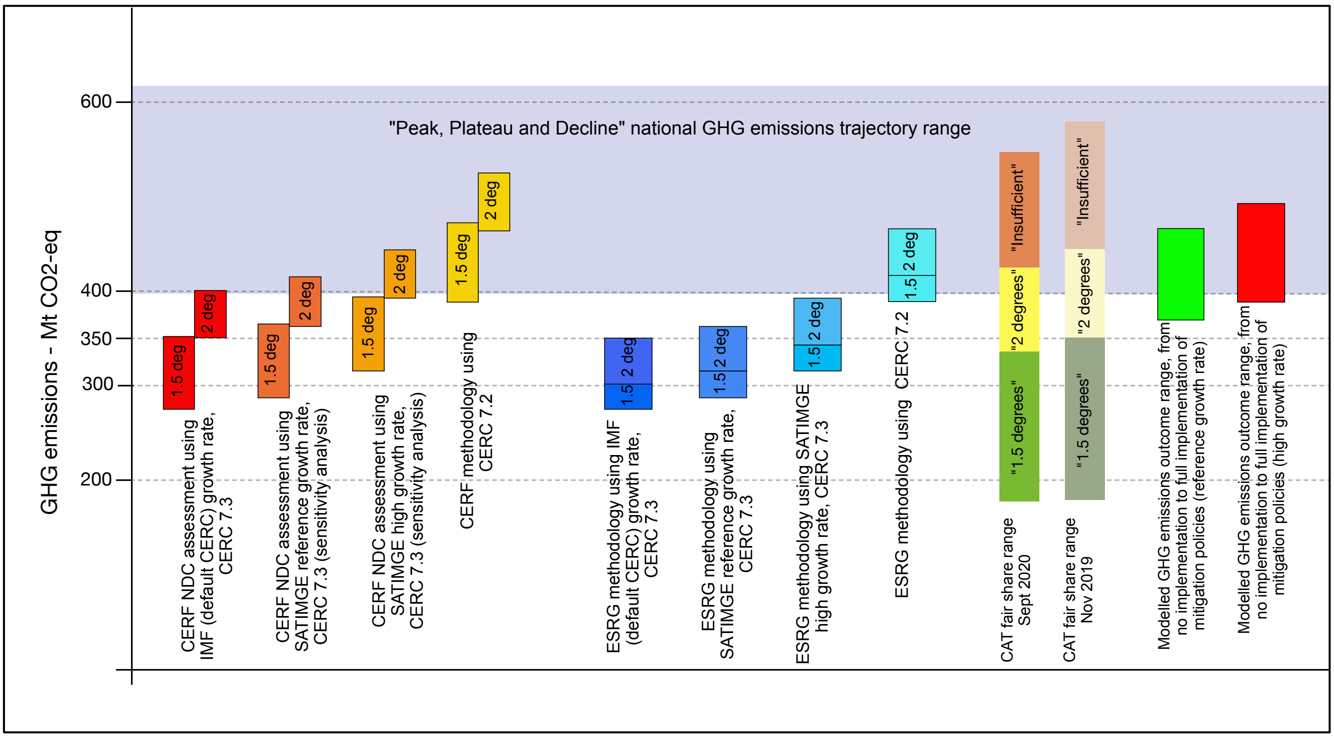

Figure 42 - Comparison of fair shares for 2030: on the left 1.5 and 2 degree ranges a) as contained in the CERF NDC assessment, b) and c) sensitivity analyses from the CERF NDC assessment using the SATIMGE growth projections, and d) the CERF assessment methodology using CERC 7.2 (the previous version of CERC which was used for the analysis here). And on the right, d), e) and f) – using the same set of growth rates and CERC 7.3, but using the ESRG methodology, and g) the current assessment using CERC 7.2 above. To the right of this is the CAT fair share range (updated – 22 Sept 2020 version), for comparison,) which is slightly lower than the version used in this analysis below – see below). All results have been adjusted to include land use emissions, to allow comparison with the proposed NDC target range. The two bars on the far right are the results of SATIMGE GHG emissions modelling (with reference and high growth rates). The top of each GHG emissions range represents GHG emissions outcomes with no policy implementation, and the bottom of each range represents emissions outcomes with full implementation of mitigation policies

The methodologies are more full explained in the "fair shares" report. The CAT ranges are self-explanatory, and the CAT methodology, and its flaws, is also fully explained in the "fair shares" report. The key driver for different outcomes for the CERC ranges relate to a) the CERF team using a different methodology, which allocates a larger share of emissions space to South Africa, and b) the key driver for the LEVEL of the ranges, the economic growth rate assumptions going forward. The post-COVID growth rate which will underlie the CERC baseline projections is very low (sourced from the IMF's World Economic Outlook report) at 1.3% until 2030. Sensitivity analyses were also undertaken by the CERF team based on the growth rates used in this study. The results of the overall analysis indicate that South Africa's "fair share" is lower than previously thought, and that as a result, the NDC target range should be strengthened to bring it into line with this lower assessment of South Africa's "fair share". This could be undertaken by lowering the bottom of the target range, without creating an additional legal obligation for the country. What would then need to be assessed is what additional effort this would require, and what additional international support this would require.

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