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Quantifying the macro- and socioeconomic benefits of a transition to renewable energy in South Africa

Part 2: Economic impacts

Faaiqa Hartley, Bruno Merven, Channing Arndt, and Gregory Ireland

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Southern Africa –Towards Inclusive Economic Development (SA-TIED)

SA-TIED is a unique collaboration between local and international research institutes and the government of South Africa. Its primary goal is to improve the interface between research and policy by producing cutting-edge research for inclusive growth and economic transformation in the southern African region. It is hoped that the SA-TIED programme will lead to greater institutional and individual capacities, improve database management and data analysis, and provide research outputs that assist in the formulation of evidence-based economic policy.

The collaboration is between the United Nations University World Institute for Development Economics Research (UNU-WIDER), the National Treasury of South Africa, the International Food Policy Research Institute (IFPRI), the Department of Monitoring, Planning, and Evaluation, the Department of Trade and Industry, South African Revenue Services, Trade and Industrial Policy Strategies, and other universities and institutes. It is funded by the National Treasury of South Africa, the Department of Trade and Industry of South Africa, the Delegation of the European Union to South Africa,IFPRI, and UNU-WIDER through the Institute's contributions from Finland, Sweden, and the United Kingdom to its research programme.

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Towards Inclusive Economic Development in Southern Africa

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Part 2: Economic Impacts

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ABSTRACT

This paper assesses the economic impacts of increased variable renewable energy deployment in South Africa for both conservative and optimistic solar PV and wind cost estimates relative to a less ambitious, constrained RE deployment programme as currently envisioned by government in its electricity planning. A linked energy-economic model is used, allowing for a consistent assessment of the economy-wide impacts of changes in the energy sector. The research finds that removing the constraints on renewable energy deployment leads to increases in real GDP and employment under conservative renewable energy costs (and to greater ones under optimistic costs), despite a decline in coal production and employment.

Keywords: Renewables, linked modelling, energy, economic impacts, computable general equilibrium

1 INTRODUCTION

While the technical issues of transitioning to cleaner electricity production have been studied, little work has been done to understand the economic and social implications of this change in South Africa. Declines in global and domestic variable renewable energy (VRE) costs over the last decade, along with South Africa's well-matched energy demand profile to renewable resources supply, are likely to result in a rising share of electricity generation from VRE technologies. Studies by Merven et al. (2018), Wright et al. (2017) and Reber et al. (2018) suggest the potential to increase the share of VRE power generation from 2.2% in 2015 to 30% by 2030 and 68% by 2050 without negatively affecting the reliability or price of electricity.

International studies (see Inglesi-Lotz 2013; IRENA 2016) have shown that renewable energy and environmental conservation on the one hand and economic growth on the other are no longer mutually exclusive, due to the competitive pricing of renewables relative to other technologies. These studies have shown a positive relationship between renewable energy adoption and macroeconomic indicators such as real gross domestic product (GDP), real per capita income, and employment.

Studies that have analysed the macro- and/or socio-economic implications of renewable energy in South Africa have largely done so in economic models alone, which, as discussed under methodology (Section 3), do not account for the technical energy system specifications or the feedbacks between the energy sector and the rest of the economy. Such assessments have focused on only one element (e.g. gross domestic production, employment or economic welfare), and do not account for the most recent developments in renewable energy costs (see AGAMA Energy 2003; Chien and Hu 2008; Borel-Saladin and Turok 2013; Walwyn and Brent 2015; Hartley et al. 2018); or they have been focused at the community level, with the aim of assessing the socio-economic development impacts of specific renewable energy projects (Wlokas et al. 2012).

This paper offers an assessment of the impacts of an increase in electricity production from renewable energy sources, such as solar PV and wind, with a resulting decrease in generation from coal. This analysis is conducted using the Energy Research Centre's (ERC) linked energy-economic model (i.e. SATIMGE) - the only model of its kind in South Africa and probably the most developed linked energy-economic model in the developing world. An older version of this model has been used in energy and climate research for South Africa (e.g. Alteri et al. 2016; Arndt et al. 2016; Caetano et al. 2017), but an updated version of SATIMGE is used in this paper and includes the most recent projections for VRE costs. The linked modelling framework combines the advantages of detailed energy and general equilibrium models and therefore allows for a consistent assessment of the impact of changes in the energy sector on various economic indicators. The effects of behavioural demand responses to changes in the electricity price are also considered in the modelling framework and affect the energy build going forward (Arndt et al. 2016).

This study builds on the VRE analysis done by Merven et al. (2018), which assesses the energy implications of lower VRE costs in South Africa in the ERC's integrated energy systems model, SATIM, which is the energy model used in SATIMGE. This paper extends that research by assessing the economic implications of increased variable renewable electricity generation in South Africa, and by highlighting the implications of changing behaviour for energy planning when considering the feedback channels between the energy sector and the rest of the economy. This paper further adds to the general body of knowledge by providing a consistent set of macro- and socio-economic results that assess the impact of VRE, including its most recent developments.

2 ELECTRICITY GENERATION IN SOUTH AFRICA

2.1 Generation mix

The South African electricity system relies heavily on coal. In 2014 coal accounted for 90% of total generation, with the balance comprising hydro and pumped storage (1%), nuclear (6%), gas/diesel (2%) and renewables (2%) (DoE 2018). On average, South Africa exports 5.7% of electricity generated to neighbouring countries and generates more than 40% of the electricity used in Africa (Eskom 2012; StatsSA 2018a). Imports account for around 4.2% of total supply (StatsSA 2018a), primarily hydropower from Mozambique. An additional 8.6GW of new coal generation capacity, specifically the Medupi and Kusile power plants, is currently under construction. Delays in construction have, however, resulted in cost overruns, increasing the expected price of electricity from these sources considerably. Electricity is a key source of energy in the country, meeting almost a third of total domestic energy demand (DoE 2018).

2.2 The coal mining sector

The importance of coal for electricity production has placed the coal mining sector and the people it affects at the centre of the discussion on energy transformation in South Africa. Electricity production is the largest consumer of coal and significant reductions in coal-generated electricity would negatively affect the sector. Further, the sector's links with other sectors in the economy mean that the net impacts on the South African economy could be significant. The data, however, shows that on a national scale, apart from its importance to electricity production, coal mining plays a small role in economic growth and household welfare. Any transition away from coal should, however, be done through a phased approach, to minimise the potential negative implications (see NPC 2018 for a further discussion on this) for the affected communities.

In 2012, the coal mining sector accounted for 2.3% of GDP (van Seventer et al. 2016) and 5% of total export value. In terms of linkages with rest of the economy, coal is primarily used in the electricity and coal-to-liquid refinery sectors, which consume 41% and 15% of total production respectively. The industrial sector is the third largest consumer, accounting for 8% of total supply. This demand comes primarily from the mining and iron and steel sub-sectors. Smaller volumes of coal are used in the agriculture, commercial and residential sectors (0.4%). Coal used in the electricity and refinery sectors is primarily low-grade, while high-grade coal is used by other sectors of the economy and for exports. In terms of backward linkages, the coal mining sector primarily demands transport services, electrical machinery and financial and business services (van Seventer et al. 2016). Overall, the coal mining sector is estimated to have a domestic output multiplier of 1.55 (in 2012) which ranks 59th in 104 sectors reported by Statistics South Africa in the Supply and Use Tables, in line with the sector median of 1.57. The sector's employment effect multiplier was estimated to be 1.93 in 2012 (83rd of 104; median: 3.19). In 2012 coal mining accounted for 0.5% of total employment (StatsSA, 2012). The 72,000 labour force largely comprises high-skilled workers (defined as having an education level of grade 12 and higher), with low-skilled workers making up only a third. The sector accounts for 1.2% of the total South African wage bill, almost 85% of it going to highly skilled workers who tend to live in middle- and high-income households (van Seventer et al. 2012).

Over the past decade, the volume of coal export and domestic sales has decreased by 16% and 17% respectively (StatsSA 2018b). This trend is likely to continue domestically as national mitigation policies and measures, including the carbon tax, raise the cost of burning coal and the use of alternative technologies increases. Rising coal prices, resulting from increasing cost structures within the sector as producers dig deeper to extract coal, will also affect domestic sales and international competitiveness (Burton et al. forthcoming). Exports are likely to be further affected by global demand, which is expected to remain flat through to 2040 due to lower gas prices, increased use of renewable energy, and improvements in energy efficiency (EIA 2017). Domestic coal sales could also be affected by decreased demand from the refinery sector. Caetano et al. (2017) and Ahjum et al. (forthcoming) argue that the demand for liquid fuels is likely to decrease as the penetration of electric vehicles increases, more alternative fuels are used, and government rolls out policies under its Green Transport Strategy, which includes mode-shifting for freight and passenger transport (DoT 2017).

2.3 The renewable electricity generation sector

Solar PV and wind electricity subsectors are included in the 2012 Social Accounting Matrix (SAM) when the electricity sector is disaggregated by technology. The methodology and data used for this disaggregation is the same as discussed in Alton et al. (2014) and is based on Pauw (2007) and StatsSA (2009). In the 2012 SAM, production by each technology – and hence the expenditure by each sub-sector – is scaled up to match actual production in that year. Employment in solar PV and wind generation is found by Pauw to be larger than in coal power generation, and Alton et al. estimate that employment in solar PV and wind production is larger than that in coal. Assuming the same average wage across technologies, they estimate that solar PV and wind employ roughly 6.8 and 2.5 workers directly per GWh of electricity produced, compared to 0.5 in the coal sector.

3 METHODOLOGY

Economic analysis of energy sector developments in economic models is often criticised for not sufficiently including the detailed technical considerations required in energy planning while maintaining the necessary economic information to be useful for policy analysis. The ERC, in conjunction with the United Nations University World Institute for Development Economics Research (UNU-WIDER) and the National Treasury of South Africa, developed a linked energy-economic model, called SATIMGE, which overcomes this shortcoming. SATIMGE combines the ERC's South African TIMES (SATIM) model (a bottom-up integrated energy systems model) with the National Treasury's eSAGE model (a computable general equilibrium model). The combined model also addresses the shortcomings of energy-only models, which include economic growth or energy demand growth in an exogenous way, not accounting for the growth impacts of changes in the energy sector (see Arndt et al. 2016 for detail on the individual and linked model(s)).

SATIMGE links the SATIM and eSAGE models in an iterative process that mimics South Africa's electricity sector planning process (see Figure 1). Energy and electricity planning in South Africa occur through the Integrated Energy Plan (IEP) and Integrated Resource Plans (IRP). These are developed by the Department of Energy and are meant to be updated every two years (DoE 2011) with new information. The linked model therefore allows the electricity build plan to be updated for future investments, but not for those that are considered to be already sunk. The electricity price is determined exogenously by the National Energy Regulator of South Africa and is based on the costs of generating electricity.

Given an initial growth projection for the demand sectors and household income, SATIM computes the least-cost energy technology mix, and the resulting investment plans. In the electricity sector, the investment (capital growth and expenditure on power plant construction), share of electricity production by technology group (via the electricity sector production function), and changes in average electricity generation cost are passed on to eSAGE, via the electricity price. In order to accommodate the fixed electricity price in eSAGE, the indirect sales tax on electricity is freed up. The problem is that if both the price and capital growth are imposed onto eSAGE for the entire model horizon, there is little room for demand to react. Demand tracks the investment (capital growth), which defeats the point of using a CGE model to estimate the demand response. To circumvent this, only the price projection and the production mix are imposed onto eSAGE for the entire model horizon in the first iteration, and capital growth and expenditure are only gradually imposed in the following iterations. The result of this is that by the end of the planning horizon the growth projection is consistent with the electricity price and can react to electricity price changes.

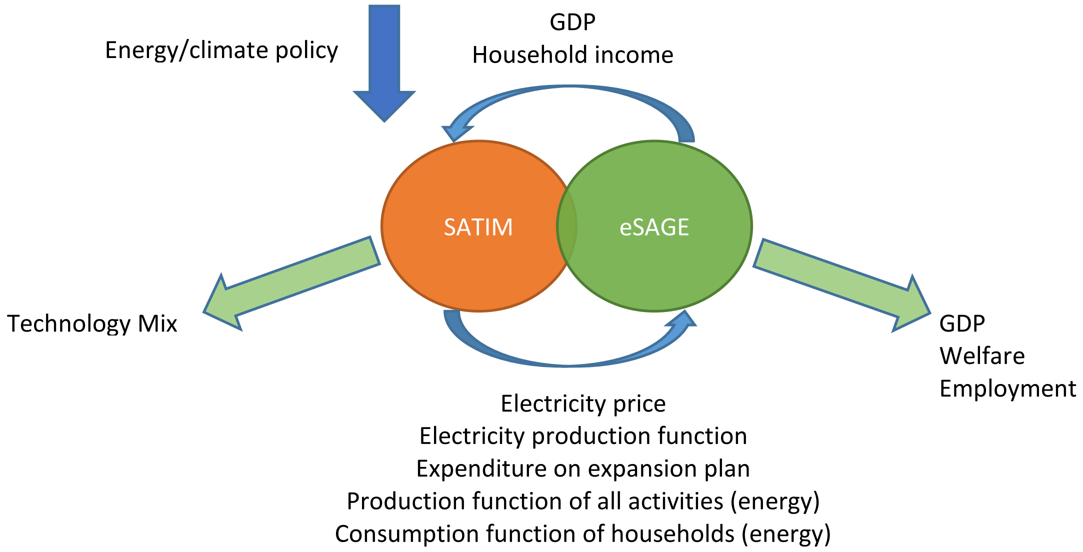
The refining sector is treated in a similar way to the electricity sector, except that in the current formulation liquid fuel prices are not imposed, nor are capital increments.

In other productive sectors (including freight transport services), activity-level changes are passed from eSAGE to SATIM via a demand module that converts the activity-level changes (sector growth) to changes in demand for energy services in the industry sectors (e.g. process heat). The final energy demand (energy mix and energy intensity) from industry is determined endogenously by SATIM. This is passed back to eSAGE via the sector production functions.

For households' income growth the different household groups are passed from eSAGE to SATIM via a demand module that converts the changes in income levels to changes in demand for energy services by households (e.g. cooking). The demand module includes a mode-switching feature for passenger transportation where mode switching is currently specified exogenously. Adjustment of household energy consumption (including energy for transportation) based on the results of SATIM are made to the household consumption function in eSAGE.

After five iterations, the energy utilization (and associated CO_2 emissions) in both models are aligned and internally consistent in terms of demand, price and mix.

Figure 1. Iterative process undertaken by SATIMGE



Source: Updated from Arndt et al. (2016)

In this paper an updated version of SATIMGE is used to analyse the impacts of increased VRE deployment in South Africa. The updates to SATIM are discussed in Merven et al. (2018). The eSAGE model has been updated by including a more recent and detailed SAM and newer behavioural elasticities. The SAM has been updated to 2012, which serves as the calibration point for the CGE model. The initial 2012 SAM developed by van Seventer et al. (2016) was disaggregated to include detailed electricity and refinery technologies. The mining sector was disaggregated to reflect the existing crude oil and natural gas sectors, while the potential for hydrogen production was also included. The petroleum commodity was expanded to reflect the difference in diesel and petrol use for transport and industrial purposes, and other liquid fuel use. The 2012 energy balance developed by the ERC was used to inform these changes (see Merven et al. 2018). Other subsectors were aggregated such that the SAM comprises 67 activities and 55 commodities. Four categories of labour, distinguishing between skill level (determined by education), are included.[1] To further highlight the differences between the energy and non-energy sectors, capital is disaggregated between energy and non-energy capital. Households are divided into 14 representative groups and represent the decile income distribution, with the wealthiest 10% of households further disaggregated into five groups to capture the differences in incomes at this level. Other institutions – government, enterprises and the rest of the world – are also represented. Table 1 presents the structure of the South African economy as captured in the 2012 SAM.

[1] Skills levels are classified as primary, middle, secondary and tertiary. Primary refers to workers with some or no primary schooling, i.e. grades 1–7. Middle includes workers who have completed grade 10. Secondary includes workers who have completed grade 12. Tertiary includes workers who have at least some post-secondary or higher education.

Table* 1. *Structure of the South African economy, 2012

	Percentage share of			
	Value added	Employment	Exports	Imports
Total	100.0	100.0	100.0	100.0
Agriculture, fishing and forestry	2.4	4.8	2.5	1.2
Mining	9.4	2.6	35.2	10.1
Coal	2.3	0.5	5.0	0.0
Manufacturing	12.9	12.6	44.9	73.3
Other industry	6.8	8.3	0.9	0.6
Electricity	2.9	0.5	0.8	0.5
Trade, hotels and accommodation	12.0	21.8	2.8	3.0
Transport and communication	9.2	6.0	4.5	4.0
Financial and business	19.2	13.2	7.2	5.6
Government	16.5	6.2	0.1	0.0
Other services	11.6	24.6	2.0	2.1

Source: Energy extended 2012 SAM of South Africa

Elasticities used in the model were updated with the most recent published estimates for South Africa. Income elasticities were based on estimates by Burger et al. (2015), Armington trade elasticities were based on estimates by Saikonnen (2015), and factor elasticities were based on Kreuser et al. (2015).

4 SCENARIOS AND ASSUMPTIONS

The scenarios considered in this study are aligned to those reported by Merven et al. (2018). This is done so that the energy planning implications of using a linked energy-economic model can be assessed while still conducting an economic analysis (see Table 2). These scenarios are chosen in order to highlight the potential implications of optimal VRE inclusion in the electricity energy mix with and without constraints placed on the system, as well as under conservative and optimistic VRE price projections. South Africa's current energy build plan constrains the capacity build of solar PV and wind at 1GW and 1.8GW per annum and restricts the share of peak demand met by distributed VRE to 15% (DoE 2016).

Table 2. Scenarios modelled in SATIMG

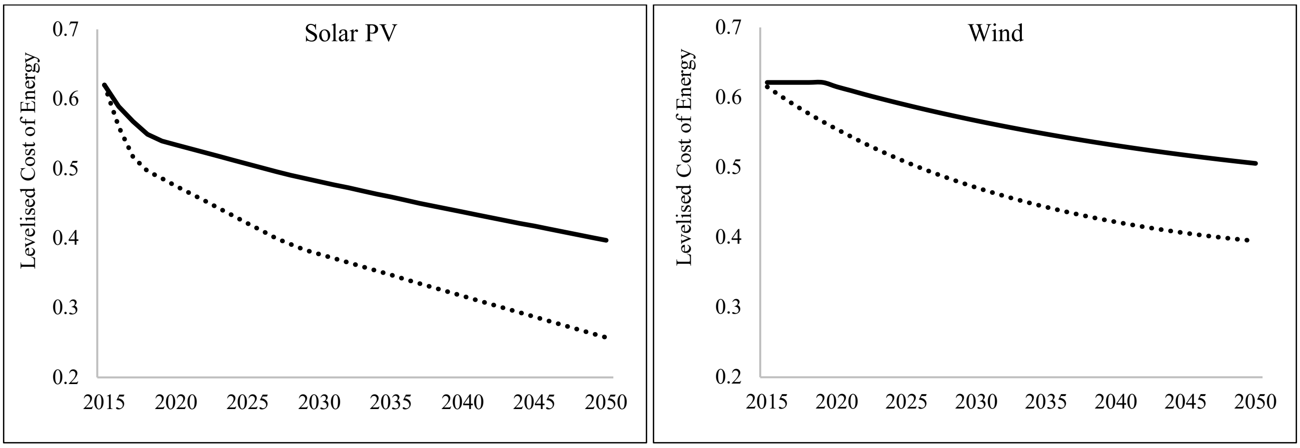
Scenario	Description
CONALLRE	***Constrained renewable energy***. This scenario imposes the current VRE constraints imposed by the South African government. Conservative costs for solar PV and wind are included.
UCONCRE	***Unconstrained renewable energy***. This scenario builds on CONALLRE with the difference being that the VRE constraints are removed.
CONALLRE-L	***Constrained renewable energy with lower renewable costs***. This scenario is the same as CONALLRE, but optimistic costs for solar PV and wind are included.
UCONCRE-L	***Unconstrained renewable energy with lower renewable costs***. This scenario builds on CONALLRE-L with the difference being the build and central distributed constraints are removed.

Source: Adapted from Merven et al. (2018)

Average annual growth over the 2018-2050 period in the CONALLRE scenario is aligned to the 3.1% moderate growth projection of the 2016 Draft IRP. The structure of the economy does not shift dramatically although the share of mining in gross value added (GVA) decreases, while agriculture and manufacturing increase marginally. The supply of labour is assumed to increase in line with population growth (~0.56%, UNEP 2016), although upward sloping labour supply curves are assumed for all skill categories, given the long-term nature of the analysis. Government spending and foreign savings increase by 3% per annum, although the increase in foreign savings decreases over time as debt is repaid. Total factor productivity is adjusted to reach the 2016 Draft IRP moderate growth forecast. The macroeconomic closures included are aligned to the stylized facts for South Africa; it is assumed that investment is driven by the total level of savings in the economy; that government savings are flexible, and no fiscal rule is imposed; and that the exchange rate is flexible. Existing capital is assumed to be fully employed and activity-specific.

Solar PV and wind costs included in the SATIM model are illustrated in Figure 2, where the solid line presents the conservative costs included in this study and the dashed line presents the optimistic costs.

Figure 2. Levelised cost of energy: 2015–2050 (2016 R/kWh)



Source: Ireland and Burton (2018)

Energy sector CO_2 emissions are constrained to meet South Africa's mid-PPD commitment (RSA 2011) using a cumulative CO_2 constraint over the whole energy sector, leaving the least cost path to allocate sector emissions trajectories.

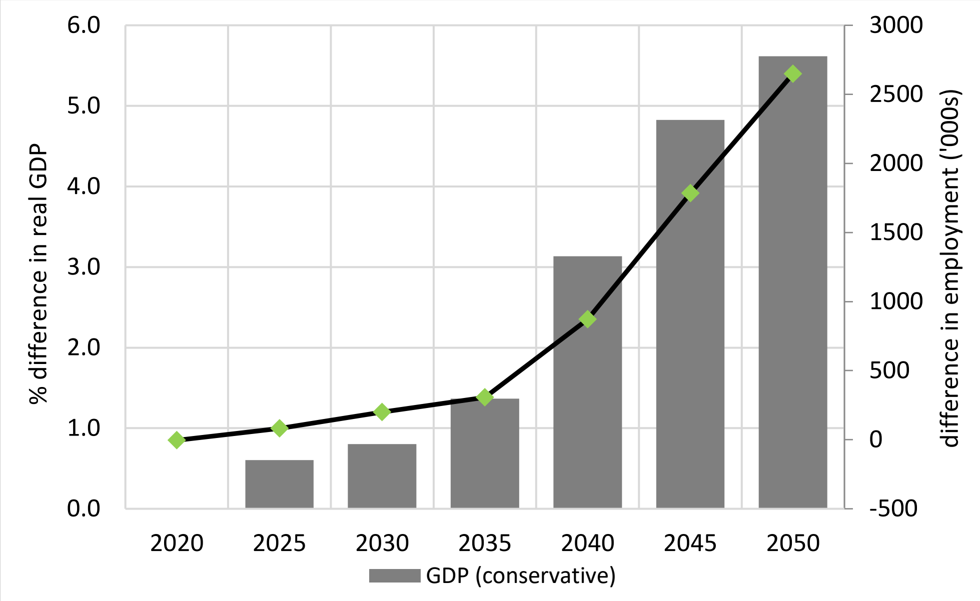
5 RESULTS

This section discusses the economic impacts of increased VRE deployment in South Africa. As reported by Merven et al. (2018), removing the constraints on VRE builds in the UCONARE scenario results in an increase in renewable energy capacity in the electricity mix in South Africa. Specifically, their findings show that the share of VRE increases to 72% by 2050 under a conservative cost assumption and 77% under an optimistic cost assumption. This section is divided into three subsections. The first two report on the aggregate economic impacts of increased VRE deployment, comparing scenario UCONCRE to CONALLRE, and on the sector dynamics underlying these aggregate impacts with a focus on changes in the mining sector. The third subsection assesses the differences in economic impacts in a lower renewable cost environment. The results are reported for 2030 and 2045, providing a medium and long-term view of the economic impacts.

5.1 Aggregate impacts

On aggregate the increased deployment of VRE in the UCONCRE scenario results in an increase in the level of real GDP and employment (see Figure 3). The increase in real GDP is driven by the lower overall level of investment required over the period – cumulative investment is 9.2% lower in the unconstrained case - and the lower electricity price. Total investment in the electricity sector is higher in the CONALLRE scenario due to the use of more expensive technologies. As a result, the electricity price in the CONALLRE scenario is also higher as the higher investment costs translate into higher capital repayments. The difference in electricity investment and price is presented in Figure 4.

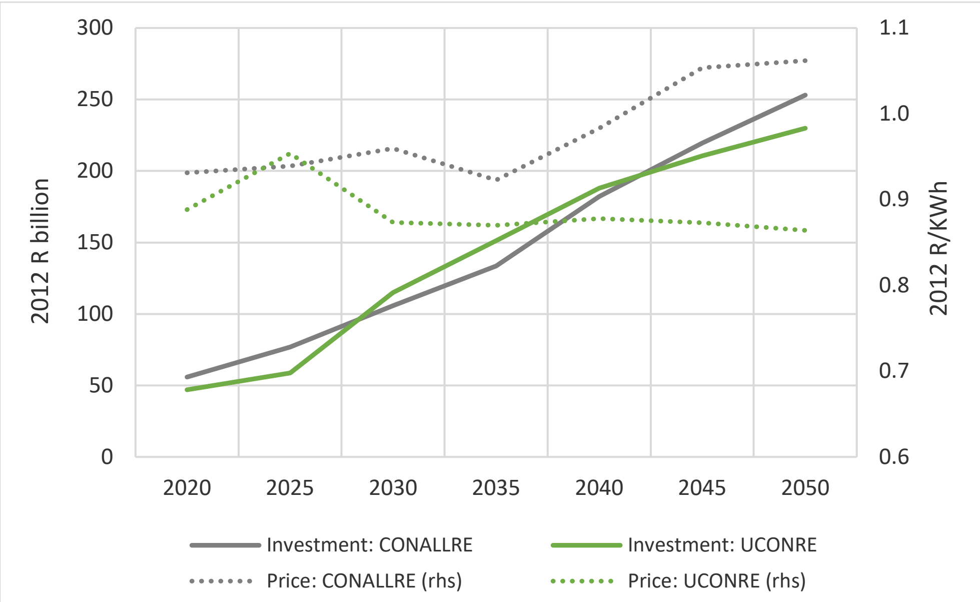
Figure 3. Real GDP and employment impacts (five-year intervals)



Source: Model results

In the modelling framework, it is assumed that a fixed amount of funds is available for investment in the economy. Funds required for electricity investment are allocated first from this pool. Other sectors in the economy compete for the remaining funds. This arrangement ensures that the opportunity costs of investment are captured within the modelling framework. The lower level of investment required under the UCONCRE scenario means that more funds are available for the expansion of other sectors in the economy.

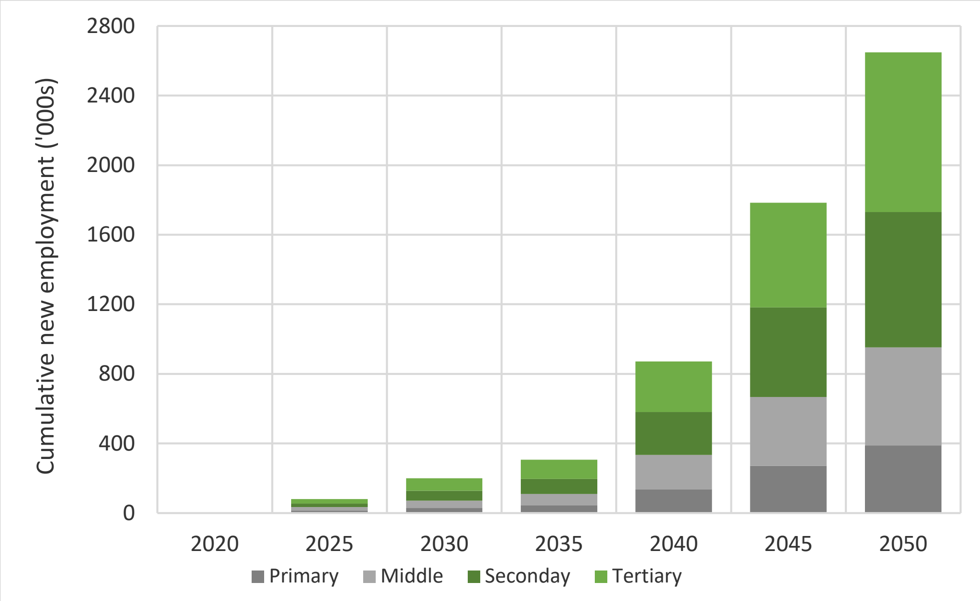
Figure 4. Electricity investment and electricity price (five-year intervals)



Source: Model results

The lower electricity price supports sector economic growth as it decreases production costs and thus increases profitability. By 2030 and 2050, the electricity price is respectively 6% and 20% lower in the unconstrained RE scenario (i.e. UCONRE). Lower electricity prices also increase household disposable incomes, resulting in increased demand for goods and services. The combination of these enable an expansion in activity in the economy creating a demand for labour. Net employment increases by 0.8% and 5.5% by 2030 and 2050 respectively. This result, however, is dependent on enough labour being available to meet demand such that crowding out by rising real wages in the economy does not occur. The increase in employment, relative to the constrained scenario (i.e. CONALLRE) after 2040 is also the result of slower employment growth in the CONALLRE scenario as electricity investment increases crowding out expansions in other sectors of the economy when compared to the UCONRE scenario. The increase in employment is focused in the secondary- (Grades 10-12) and tertiary-educated (post Grade-12) labour groups, although employment opportunities are also created for lower educated workers, i.e. primary and middle school educated labour (< Grade 10) (see Figure 5).

Figure 5. Employment impacts by skill level (five-year intervals)



Source: Model results

Household welfare, measured by real household consumption, increases in the UCONCRE scenario. By 2050, real household consumption is 6% higher with similar increases experienced by poor and non-poor household groups. The increase in welfare is driven by increased income from labour and capital as well as lower electricity prices. Welfare increases in both poor and non-poor households, although non-poor households experience a marginally higher growth rate.[2]

5.2 Sector impacts

The increased use of renewable resources in the electricity generation mix leads to a faster decline in coal-generated power (Merven et al. 2018). The electricity sector is the largest consumer of coal, specifically low-quality coal. Coal-powered generation decreases from 88% of total electricity supply in 2012 to 52% in 2030 and 50% in 2050 in the CONALLRE. The demand for low quality coal in the power sector therefore also decreases, falling from 120 million tons (MT) in 2012 to 101 MT in 2030 and 48 MT in 2050. In the UCONRE scenario, the share of renewable energy increases by a larger margin, displacing more coal – the share of coal in total electricity production declines to 43% by 2030 and 11% by 2050. Under this scenario, the demand for coal by the power sector declines even further, to 72 MT in 2030 and 24 MT in 2050.

While demand for low quality coal decreases, demand for high quality coal used by other sectors, specifically industry, increases (see Figure 6). Industry demand for coal is driven by increased demand for process heat. Coal exports increase in the medium term to 2030, reaching around 92 MT in CONALLRE from 82.7 in 2012. Exports of coal thereafter decrease. The ability of the coal sector to switch to supplying foreign markets is limited by existing rail capacity (Transnet, 2017) and lower expected future coal prices. Coal exports could decline to lower levels than presented here if traditional global markets reduce demand significantly as a result

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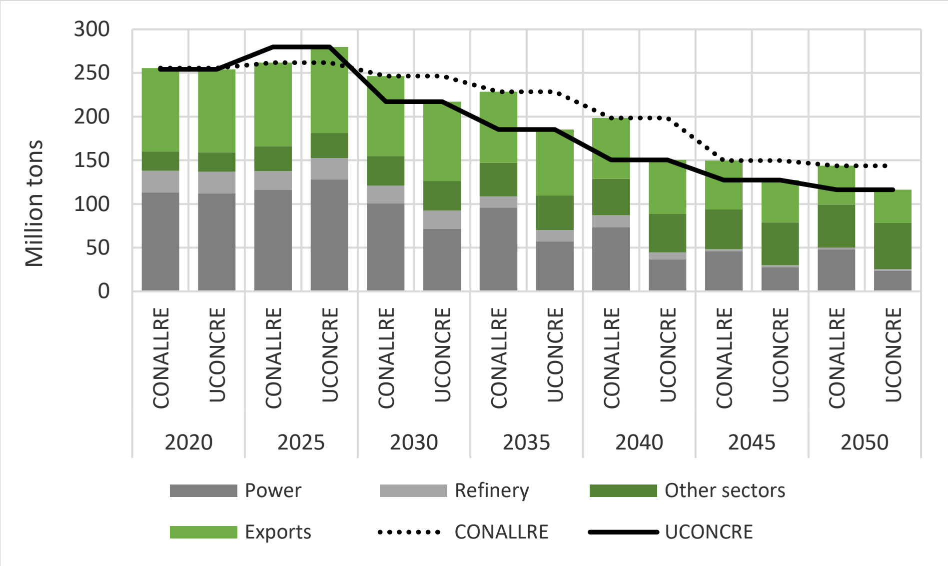
[2] Poor households are defined as those in income deciles 1 to 4 and non-poor households are defined as those in income deciles 5 to 10.

of shifting to cleaner technologies. The decline in coal demand in both the CONALLRE and UNCONRE scenarios results in a decline in employment in the coal sector by 0.3% per annum over the period.

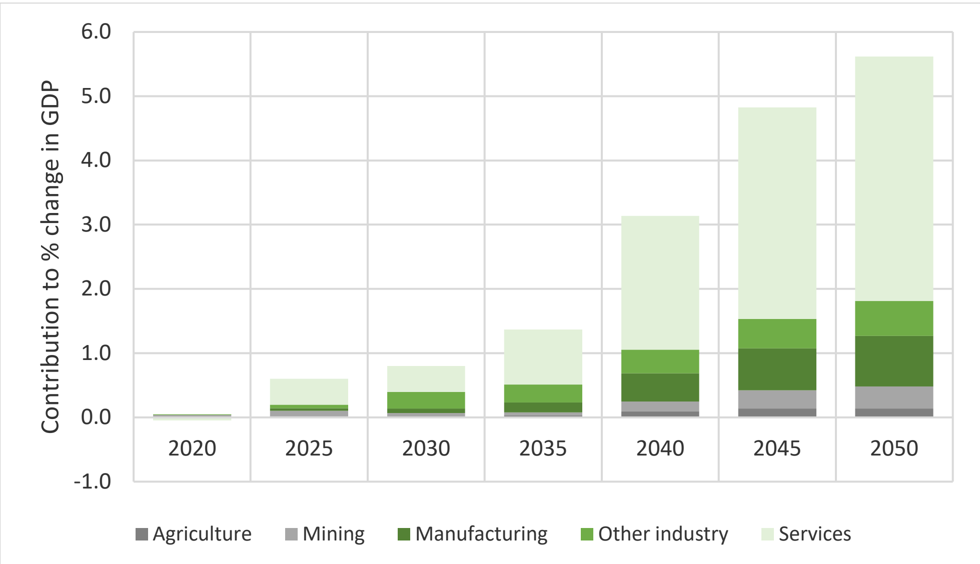
Figure 6. Coal demand (excluding residential) (five-year intervals)



Source: Model results

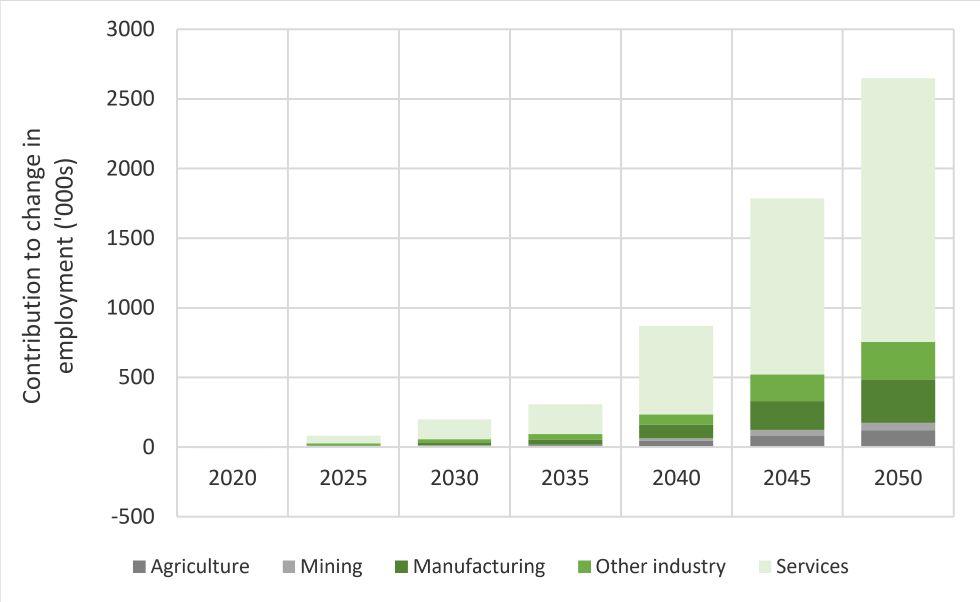
Real GVA is higher in the UCONRE scenario across all sectors with the largest increases experienced in the services and electricity sectors (see Figure 7). Service sector growth is driven by financial and business, and transport and communication. Real GVA in the electricity sector increases due to increased demand: by 2050 electricity demand is 3.3% higher than in the CONALLRE scenario. Declines in GVA are primarily experienced in the coal mining sector, although overall mining activity increases. Growth in the mining sector is driven by increased metal ore and other minerals mining. Employment is driven by increased jobs in the services sector. The manufacturing sector creates the second largest number of jobs followed by the electricity sector (see Figure 8). Job creation in the electricity sector is partly driven by the higher employment intensity of solar PV and wind generation per GWh relative to coal.

Figure 7. Sector contributions to the change in GDP (electricity sector included in Other industry) (five-year intervals)



Source: Model results

Figure 8. Sector contributions to the change in employment (electricity sector included in Other industry) (five-year intervals)

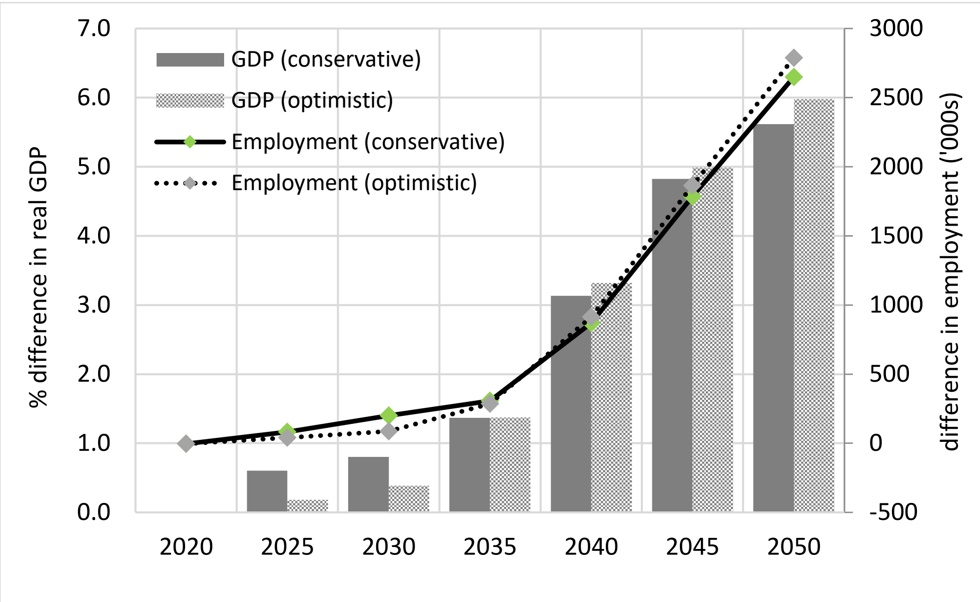


Source: Model results

5.3 Optimistic renewable energy prices

The results presented thus far consider the economic impacts of increased VRE under conservative costs. As highlighted by Ireland and Burton (2018), it is highly probable that the cost of renewable energy would continue to decrease going forward as technology and learning improves. For this reason, Merven et al. (2018) also consider a more optimistic renewable energy price environment. An environment with lower VRE costs has a larger positive impact on real GDP and employment, as illustrated in Figure 9. The larger GDP and employment impact is driven by lower electricity investment requirements and lower electricity prices. Household welfare is also higher, increasing by 6.4% relative to 6.0% under conservative renewable costs.

Figure 9. Real GDP and employment: conservative vs optimistic renewable energy costs (five-year intervals)



Source: Model results

6 DISCUSSION

The results from the study presented here highlight that a shift to increased VRE generation will have a positive impact on real GDP and employment in South Africa. The increase in production is the result of lower electricity investment requirements, limiting the crowding out of electricity investments on the economy, as well as lower electricity prices. More favourable renewable energy costs, which are likely in the future, are shown to have a larger positive impact on real GDP, employment and welfare. These positive impacts depend, however, on the availability of labour resources required for the transition – primarily workers with at least a Grade 12 level of education. Lack of supply for labour demanded will reduce the positive impact of increased VRE deployment as sectors compete for labour, resulting in rising production cost structures and prices which will negatively affect demand.

The net positive gains are experienced across sectors in the economy but are concentrated in the electricity and services sectors. A decrease in coal mining production is experienced in the unconstrained scenarios (relative to constrained scenarios) although a shift in production to high quality coal for increased industry demand provides some support to the sector. The negative impact on the coal mining sector (which is highly likely regardless of VRE, given rail capacity constraints), lower expected global coal prices, and potentially lower global coal demand, is one that must be managed and mitigated as far as possible, particularly in areas where coal mining is the primary employer and source of income. The impact of changes in the coal mining sector at the provincial or community level requires further research. The economic modelling framework in this study provides for a limited ability to switch from low to high quality coal mining without incurring any additional costs. Further research is required in this area to assess whether this is the case. More detailed information regarding the cost structures of low versus high quality coal would also add value to work.

While a decline in coal mining production and employment is probable, other opportunities may, however, be on the horizon for the South African mining sector. The global increase in electric vehicle demand and hence batteries for these, has increased the demand for metals such as cobalt, copper and nickel. While these are currently not large mining sub-sectors in South Africa the potential, and natural resource availability, does exist for these sub-sectors to be expanded. Further research is required to better understand the prospects of higher global demand of these metals for the South African mining sector.

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