Quantifying the Macro- and Socio-Economic Benefits of a Transition to Renewable Energy in South Africa

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Abstract: For decades cheaper and easily available fossil fuels has underpinned the energy system of South Africa inhibiting the potential for a sustainable low carbon economy. Favourable developments in renewable energy technologies, and prices, provides an opportunity for the country to significantly reduce its emissions without sacrificing economic development. This paper assesses the technical potential for renewable technologies in electricity production and the associated economic implications of a transition to renewable energy in South Africa. This is done by comparing two energy pathways for the country, one in which the deployment of renewable technologies is constrained and another in which it is not. Our findings show that over the next two decades renewable energy technologies will become the largest contributor to electricity generation in the country under least cost unconstrained planning. At the national level the shift to renewable energy has a positive impact on real GDP and employment despite the presence of a smaller coal mining sector.

The contours of the global power sector are changing rapidly due to ongoing technological advance, particularly in the renewable energy space. Since 2008, the solar module price index has fallen roughly by a factor of five with the price of wind declining by a factor of two. Gains in systems integration, notably the ability to accommodate variable renewable energy supplies on a system wide basis, are not as easily quantified but have also been dramatic. With these advances, the economics of power systems are changing. This is evident in global power generation investments which were twice as large for renewables than fossil fuels in 2016 with 161 GW of renewables being installed.

South Africa has a coal-based energy system, which has been in the past a source of abundant and cheap energy. This coal-based system is ageing and given climate and environmental concerns, there are good reasons for South Africa to embark on a clean-energy transition. Fortunately, South Africa is also well endowed in solar and wind energy resources (Ireland 2017). This combined with the recent and projected future improvements in wind and solar technology offers South Africa a real opportunity to make the transition without compromising its other development objectives such as poverty reduction and improved welfare. 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, finding a positive relationship between renewable energy adoption and macroeconomic indicators such as real gross domestic product (GDP), real per capita income, and employment. South Africa's energy dependence on coal has however been a key supporter of the coal mining industry which is concentrated in two provinces (namely Mpumalanga and Limpopo) providing a large of employment and income to people in these regions. Development concerns regarding a shift to renewables is therefore high.

This paper aims to contribute to the discussion on the energy transition in South Africa by assessing the role of renewables in energy supply; and quantifying the economy-wide impacts of changes in the energy system. This paper differs from other studies in that it a) considers the impacts of technology developments in the full energy system and not only the electricity sector as in other studies; b) assesses the economic and development impacts in an economy-wide model enabling an assessment of the impacts in specific sectors such as the coal mining sector; and c) does both a) and b) in a consistent modelling framework thus ensuring that behavioural responses to changing prices (i.e. fuel switching, efficiency gains and volume changes) are accounted for in both the energy system outcome and economic impact. This is enabled through the use of a hard-linked energy-economic model of South Africa called SATIMGE which was developed by the Energy Research Centre (ERC) at the University of Cape Town, the United Nations University's World Institute for Development Economics Research (UNU-WIDER) and the National Treasury of South Africa.

A linked approach to energy and economic analysis

Energy planning and economic analysis has often been done in isolation or through soft linkages in which energy information is passed to economic models to assess the effects on the economy. These types of approaches are insufficient as a comprehensive analysis as they fail to account for the key linkages between the energy system and the economy including resource use and price and behavioural effects. In this paper we use a hard-linked energy-economy model, called SATIMGE, to obtain the optimal energy pathway for South Africa while at the same time assess the impacts of these changes on economic development.

Unlike other energy-economic models which include either a simplified version of an economic model into an energy model or vice versa, SATIMGE combines a bottom-up integrated full sector energy systems model with a detailed dynamic recursive computable general equilibrium model of South Africa (see Arndt et al. 2016 for detail on the individual SATIM and eSAGE models comprising SATIMGE). By combining these detailed models of different aspects of the country, SATIMGE is able to capture all the technical detail needed for full sector energy systems modelling and assess the impact across various agents in the economy considering behavioural responses to relative price changes.

SATIMGE links the SATIM and eSAGE models in an iterative process (see Figure 1) that mimics South Africa's electricity sector planning process in which energy investment and pricing decisions are taken outside of the market. New energy and electricity investment is determined by the state Department of Energy, with updates expected every two years (DoE 2011), while electricity prices are set by the National Energy Regulator of South Africa. Specifically, SATIM, given initial sector and household income growth projections, is used to compute the least-cost energy technology mix, resulting investment plan and electricity price. This information, along with information on fuel efficiency and fuel switching is passed on to eSAGE which is run to incorporate the new energy supply and demand composition. Investment is determined in eSAGE based on closure rules imposed on the model. In the version deployed here, fixed savings rates plus a fixed flow of foreign savings determine the pool of investable funds. Electricity investment is allocated from this pool. Other sectors in the economy compete for the remaining funds. This arrangement ensures that the opportunity costs of investment between sectors are captured within the modelling framework. Updated sector and household income growth projections are then passed back to SATIM which optimises based on this new information. This iterative process continues until the model converges such that energy utilization (and associated CO_2 emissions) in both models are aligned and internally consistent in terms of demand, price and mix. 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. The SATIM and eSAGE models are calibrated based on the 2012 energy balance and social accounting matrix (van Seventer et al. 2016) respectively.

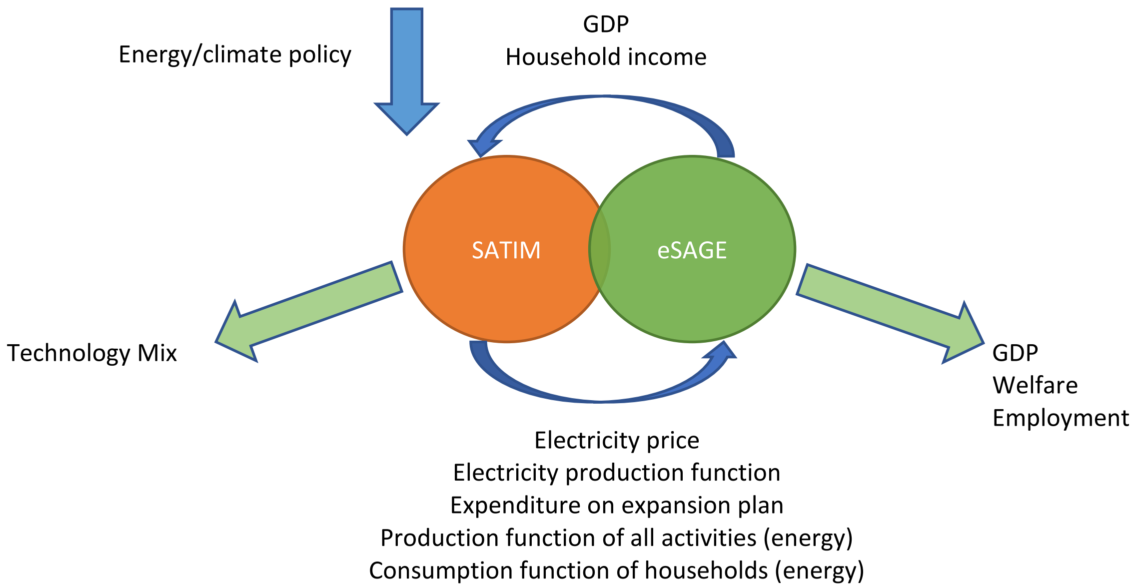

Figure 1: Iterative approach used in SATIMGE (Updated from Arndt et al. 2016)

Two scenarios are used to assess the impacts of renewable technology developments on the electricity system (within the larger energy system) and economy. The first scenario (CONALLRE) considers the optimal energy mix for meeting South African demand at the least cost with constraints on renewable capacity additions as is currently the case in national planning (DoE 2016). Specifically, solar PV and wind additions are capped at 1GW and 1.8GW per annum. A 15% restriction is also placed on the share of peak demand met by distributed renewable energy. The second scenario (UCONRE), is the same with the constraints on renewable energy removed. Conservative costs by Ireland and Burton (2018) are used for solar PV and wind. Additional scenarios using more optimistic costs are also run and briefly presented in the results section.

The existing stock of technologies (e.g. power plants, refineries, vehicle parc), and committed build to 2022, are included in the SATIM model with existing power plants retired as specified by government (DOE IRP 2016). Technology costs are aligned to that used in national government planning (DOE IRP 2016) except for renewable energy costs which have been updated as per (Ireland, 2017). 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. Demand profiles for all end-uses are assumed to be fixed over time. Fuel switching for thermal and transportation energy services is allowed. The overall demand profile seen by the grid will vary over time because of differing growth rates by different sectors, fuel switching to and away from electricity, and distributed generation and storage installations. System adequacy is insured by imposing an overall reserve margin of 15% of firm capacity over peak demand. Thermal plants (including CSP with storage), hydro, pump storage and batteries are given a full capacity credit. PV is given no capacity credit. Wind is given a 15% capacity credit. PV and wind profiles are aggregated to the 8 time slices used in this model from the profiles used in (Wright et al. 2017, Reber et al. 2018).] Coal and nuclear based technologies are given limited flexibility in that they are not permitted to vary their output during the day.

Real GDP growth in the CGE model is targeted to meet actual growth between 2012 and 2017, whilst growth between 2018 and 2022 are based on projections from the National Treasury and International Monetary Fund. Longer term growth projects are aligned to meet the Department of Energy's planning growth rate of 3.2% to 2050. The structure of the economy does not shift dramatically although the share of mining in Gross Value Added (GVA) decreases, while the share of 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 increases by 3% per annum. Foreign savings increase initially at 3% per annum with this rate decreasing 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; government savings are flexible, and no fiscal rule is imposed; and the exchange rate is flexible. Existing capital is assumed to be fully-employed and activity specific. Elasticities used in the CGE model are based on the most recent published estimates for South Africa: income elasticities (Burger et al. 2015); armington trade elasticities (Saikonnen 2015); and factor elasticities (Kreuser et al. 2015).

The role of renewables in power generation

In a least cost optimisation scenario in which the inclusion of renewable energy is not constrained (i.e. UCONRE), grid-based generation capacity shifts from being coal dominant to renewables dominant by 2030 with only Medupi and Kusile coal plants left in the system by 2050 (see Figure 2). New capacity additions of wind and solar are 65GW and 55GW between 2025 and 2050 (some of which retires during the period) with smaller additions of 3GW and 37GW of batteries and gas also taking place. This translates into an investment of R229.9 bn over the period. While this investment is large, it is not totally unheard of and has already been observed in other parts of the world such as Germany and the UK. Very little new investment is made before 2025 as the system remains in excess capacity.

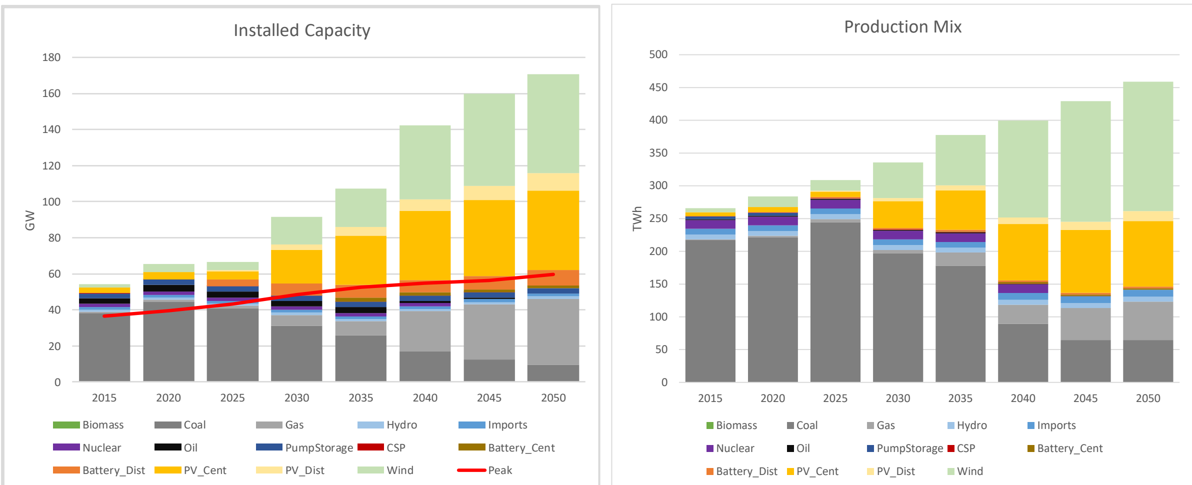

Figure 2: Total installed capacity and production in the electricity sector

The renewable energy share of generation grows to around 68% in 2050. The high renewable energy share from 2040 onward is made possible because of the highly complementary solar and wind resource profiles and the use of flexible gas generators and storage technologies in hours of low wind and solar resource availability. The remaining coal and nuclear stations provide a steady supply. These results are comparable to Wright et al. (2017) [1] and Reber et al. (2018), although in the latter more wind and gas and less PV and storage is used. For the electricity sector, Wright et al. (2017) and Reber et al. (2018) do extensive adequacy testing at very high temporal resolution. That the renewable energy share, both in terms of capacity and production, obtained here is not significantly higher than in these studies provides some confidence that the capacity expansion plan from the SATIM model would also meet system adequacy requirements.

The sum of the unitized electricity cost components, which can be interpreted as the average electricity price, stabilizes at R1.10 per kWh in 2040. The higher price is driven by the increase in capital repayments due to the capital requirements of the installed wind and solar. The expenditure on coal is partly replaced by expenditure on natural gas. The increase in unit price before 2040 is due to the completion of Medupi and Kusile.

Increased renewable energy deployment lowers South African CO_2 emissions

Increased renewable energy deployment decreases CO2 emissions in the power sector from 250 Mt per annum in 2015 to less than 100 Mt in 2050 (see Figure 3), with its share in overall energy sector emissions declining from around 55% to 28%. Overall emissions in the energy system declines largely due to the power sector highlighting the attractiveness of the power sector in mitigation relative to the others (transport, industry, commerce).

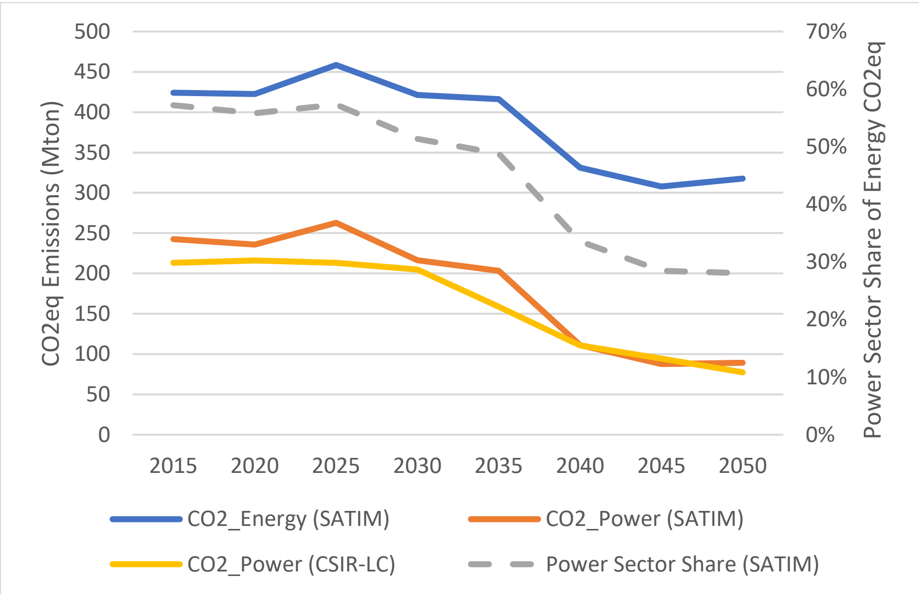

Figure 3: CO_2 Emissions from the energy system and power sector

[1] More specifically the Least Cost (Low Demand) scenario, where the demand is more comparable to the one in SATIM.

Constraining renewable energy deployment raises the costs of power generation

Imposing annual build constraints on solar PV and wind, as done in government planning, decreases solar PV and wind capacity included in the energy system by 50% (see Figure 4) with the gap in capacity covered by 800 MW of solar CSP and 6GW of nuclear, to help meet the CO_2 constraint; and an additional 10 GW of coal to replace gas. This results in a higher electricity price (the price of electricity is 14% higher in 2050) and in turn a lower demand for electricity. This combined with the fact that nuclear and coal plants run at a higher capacity factor explains why the total installed capacity is less, despite using the same demand drivers.

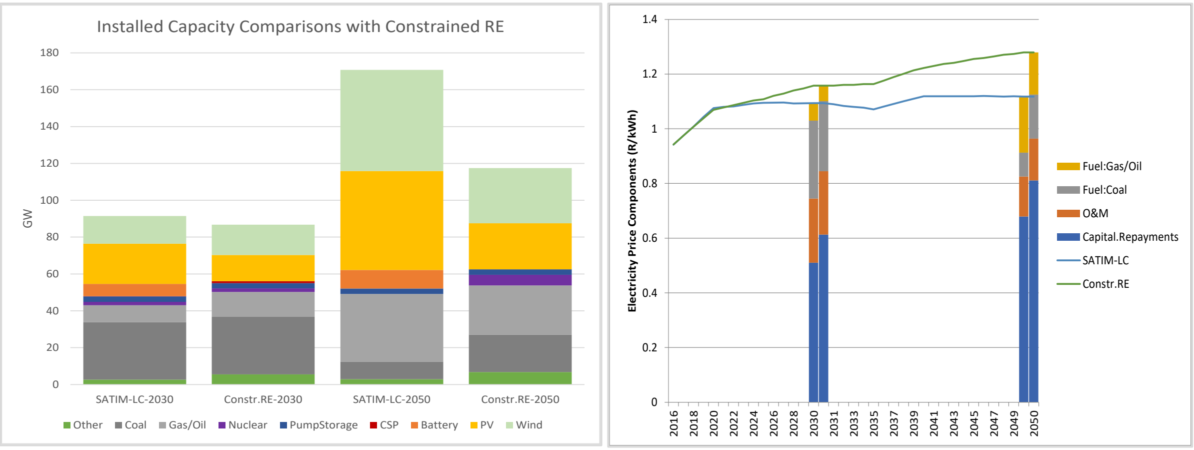

Figure 4: Comparison of total installed capacity and electricity price components

Real GDP and employment are higher when renewables are unconstrained

On aggregate the increased deployment of renewable energy in the unconstrained scenario (versus the constrained scenario) results in an increase in the level of real GDP and employment (see Figure 5). 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.

Given that in eSAGE a fixed amount of funds is available for investment in the economy , the lower level of investment required under the unconstrained scenario means that more funds are available for the expansion of other sectors in the economy.

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 scenario. Lower electricity prices also increase household disposable incomes, resulting in increased demand for goods and services.

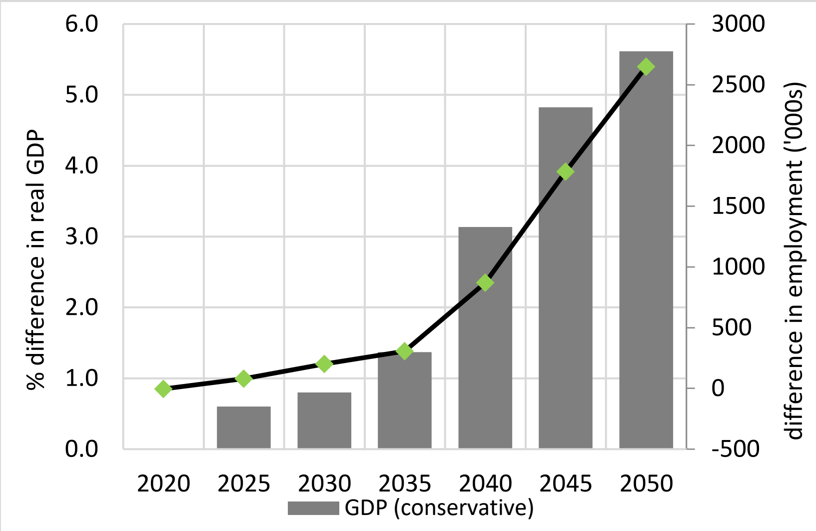

Figure 5: Real GDP and employment impacts (five-year intervals)

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 sufficient labour supply 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 after 2040 is also the result of slower employment growth in the constrained scenario as higher electricity investment requirements crowd out expansions in other sectors of the economy. The increase in employment is focused in the secondary (Grades 10-12) and tertiary (post Grade-12) educated 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).

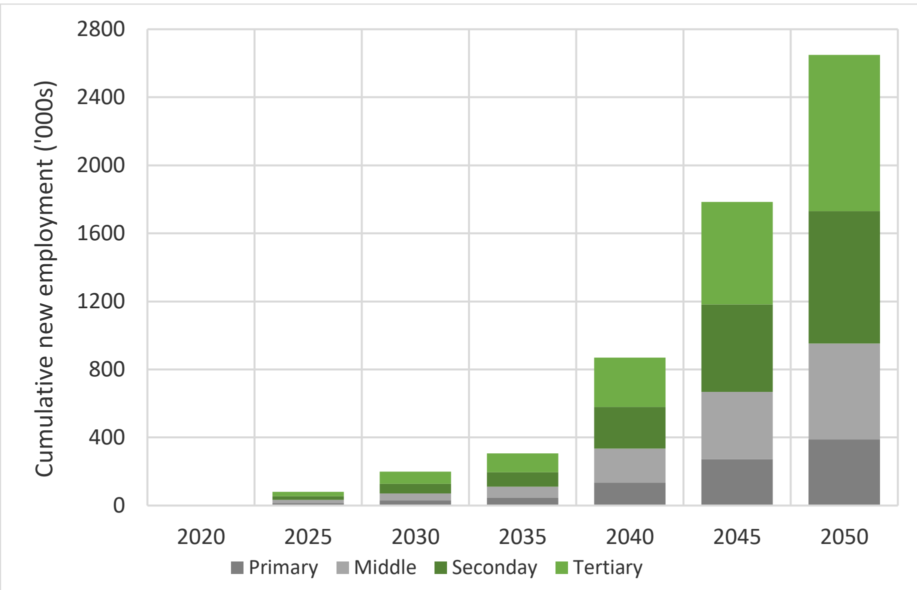

Figure 6: Employment impacts by skill level (five-year intervals)

Household welfare, measured by real household consumption, also increases in the unconstrained 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 rise in welfare.[2]

Economic benefits are broad based although coal mining activity decreases

Figure 8 presents the sector GDP and employment impacts of an increase in renewable energy deployment (defined here by the removal of renewable energy constraints). As illustrated economic activity increases across sectors, including the total mining sector despite declines in coal mining activity.

Coal mining production decreases as export demand declines to ~40 MT in 2050 from a peak of 92MT in 2030 as global demand for coal decreases as power production shifts away from fossil fuels toward cleaner energy technologies and rail infrastructure limits export capacity (Transnet 2017). The decline in coal production is also driven by a decline in domestic power sector demand. In the unconstrained scenario, coal demand from the power sector falls from 120 MT in 2012 to 72 MT in 2030 and 24 MT in 2050 (constrained scenario: 101 MT (2030); 48 MT (2050)). Demand for high quality coal used by other sectors, specifically industry, increases due to increased demand for process heat (see Figure 7).

The decline in coal demand in both the CONALLRE and UNCONRE scenarios (as depicted by the solid and dashed black lines in Figure 7) results in a decline in employment in the coal sector by 0.3% per annum over the period.

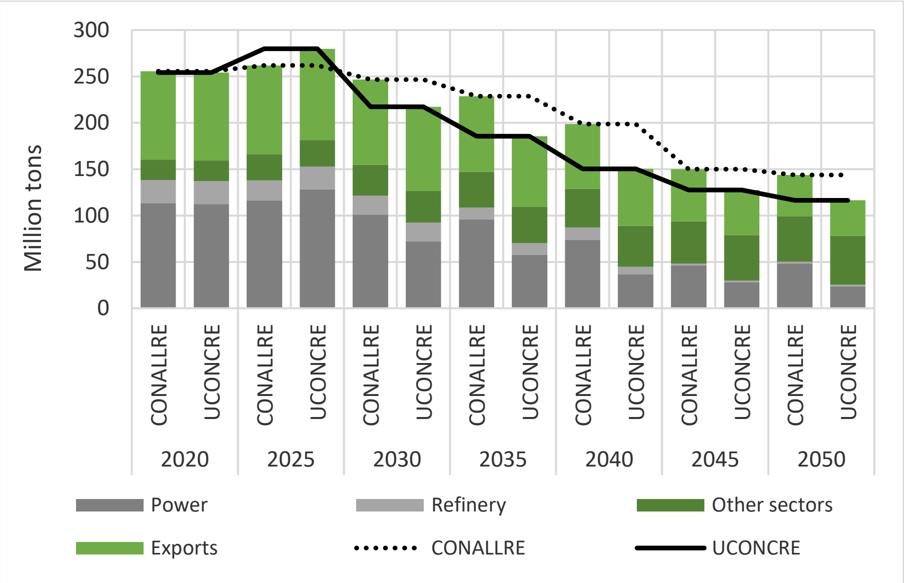

Figure 7: Coal demand (excluding residential, five-year intervals)

Growth is higher in the services and electricity sectors. In the 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 in the unconstrained scenario. Employment is driven by increased jobs in the services sector. The

[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.

manufacturing sector creates the second largest number of jobs followed by the electricity sector. 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.

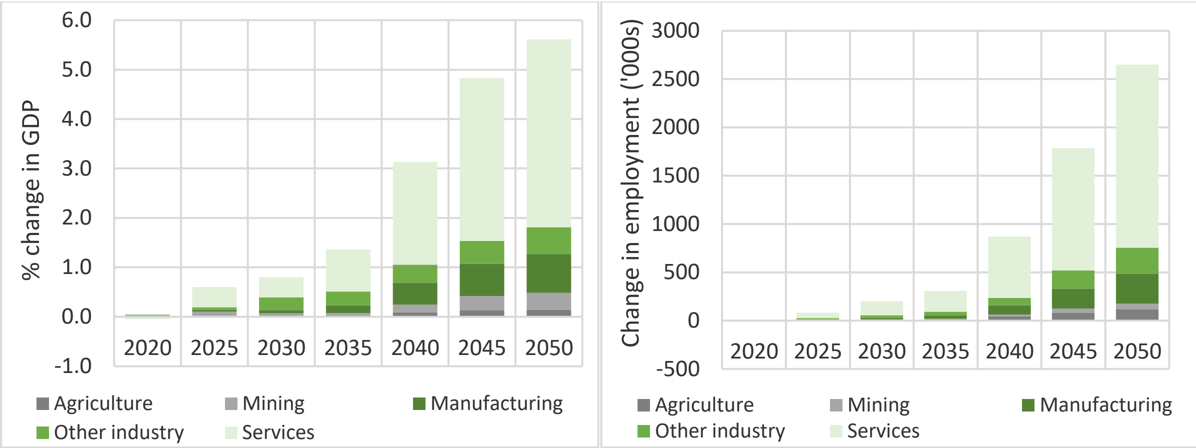

Figure 8: Sector contributions to the change in GDP and employment (five-year intervals)
**Electricity sector included in Other industry*

Gains to the economy are larger under optimistic solar PV and wind costs

The assumptions included for PV and wind costs above could be considered conservative (Ireland and Burton, 2018). Another set of scenarios were therefore modelled using more optimistic costs for PV (costs drop to $0.4/W by 2050 instead of the $0.7/W) and improvements in wind capacity factors (the wind capacity factor of new installations increase from 40% to 55% by 2050).[3] Under these set of scenarios the investment gap between a constrained renewable energy and unconstrained scenario is larger (i.e. R27.5 bn versus R23.2 bn). The deviation in the electricity price is also larger, being almost R0.18/kWh lower in the optimistic unconstrained case versus R0.16/kWh in the conservative unconstrained case. Under such conditions, the impact on real GDP and employment is also larger (real GDP: 6.4% versus 6.0%; employment: 6.1% versus 5.9%).

Discussion

This paper shows that the sector detailed but temporally and spatially aggregated energy systems model SATIM can replicate the results obtained by two recent studies using more temporally and spatially detailed models of what the least-cost power system of South Africa could look like by 2050. This was done by applying a few conservative assumptions on reserve and dispatch rules. It also provides some initial insights on the opportunity cost of over-constraining renewable technologies in the system from an average generation cost point of view. The impact of constraining renewable energy could be as high as 16c/kWh by 2050, using conservative assumptions on renewable energy and 18c/kWh, using more optimistic renewable energy costs.

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[3] Note that the SATIM uses "vintaging" of technologies, in that a wind plant built in 2020 would will retain the 2020 capacity factor throughout its life. A CF of 55% would be for plant built in 2050, not the average for all wind turbines built by then. Solar PV costs projection are based on "Scenario 3" of (Fraunhofer ISE, 2015) and wind costs and capacity factor improvement assumptions are based on (Weber et al & IEA, 2016).

The study also highlights that a shift to increased renewable energy 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 renewable energy 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 renewable energy (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 for people. 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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