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« Modelling climate mitigation and economic growth in relation to employment and skills in South Africa »

Insights from the IMACLIM-SA model

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Abstract

Our paper deals with the interaction between South Africa's carbon mitigation and employment challenges. We use IMACLIM-SA, an open-economy, 'hybrid' CGE model that projects the economy to 2035, disaggregated in 10 sectors and 5 household classes. Our model has low-, medium- and high-skill labour markets with equilibrium unemployment. We highlight problems with using a standard definition of skills as categories of educational attainment and propose three research avenues to improve modelling of skills. We then analyse a carbon tax with 5 revenue recycling options and a "positional" definition of educational attainment. A tax of 100 Rand/tCO2 recycled in sales tax cuts induces GDP and employment gains, but does not reduce inequality. A higher tax is needed to achieve South Africa's Intended Nationally Determined Contribution of the COP21. Additionally, we find that recycling carbon tax proceeds into investment in skills would already be justified if it induces a slight productivity improvement.

Keywords

South Africa, Climate Mitigation, Carbon Tax, Recycling schemes, Labour market, Skills

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1- Introduction

South Africa is a middle-income economy of high carbon intensity. Abundant coal resources and policies for energy autonomy under Apartheid led to an energy system highly dependent on coal, for electricity and even for automotive fuels from coal-to-liquid technology. In its Intended Nationally Determined Contribution (INDC) for the COP21 in Paris, South Africa however pledged to reduce its GHG emissions by 34% in 2020 and by 42% in 2025, relative to business-as-usual, and conditional on financial and technical support from the international community (UNFCCC, 2015). In 2011, South Africa had already issued a Climate Change Response White Paper (RSA, 2011), which included a carbon tax proposal planned for 2015, but now postponed to 2017 for further consultation (RSA, 2015). The South African government also acknowledged its climate change objectives in its Integrated Resource Plan (IRP), an investment plan aiming at urgently easing the tension between supply and demand of electricity (DoE, 2011).

The discussion about mitigation and energy in South Africa cannot be isolated from the important challenges facing the rapidly transforming South African society. Notably, South African economic growth has not been able to absorb the increase in labour supply from population growth (Banerjee et al., 2006). Unemployment remains high at an official rate of 25% (StatsSA, 2015), which rises to 39% when including discouraged workseekers. It is particularly prevalent among low-skill individuals, while there is a shortage of high-skill workers (Daniels, 2007). This highlights persisting inequalities within South African society, legacy of the Apartheid era. In fact, South Africa has one of the world's highest Gini indexes.

A rich and growing literature analyses the introduction of carbon taxation in South Africa. Van Heerden et al. (2006) apply a dynamic Computable General Equilibrium (CGE) model of South Africa to test different recycling schemes with different options for energy or carbon taxation. They find that notably food tax breaks offer perspectives for a 'triple dividend' of decreased GHG emissions, increased GDP and reduced poverty. De Pauw (2007) similarly relies on a dynamic CGE model to analyse the impacts of three policy scenarios with various recycling options, but he finds regressive impacts of a carbon tax on GDP and on employment, regardless of the scenario. Devarajan et al. (2011) also apply a CGE model of the South African economy, but a static one, and one focused on representing market distortions. They test the impacts of a 15% cut in CO_2 emissions by the means of a carbon tax, an energy tax or a sales tax on energy-intensive sectors. Their main result is that "labour market distortions such as labour market segmentation or unemployment due to fixed real wages and entry barriers will likely dominate the welfare and equity implications of a carbon tax for South Africa." (p.18). Finally, Alton et al. (2012, 2014) also rely on a dynamic CGE model, but one that can be linked to the SATIM energy sector model of the Energy Research Centre (ERC) of the University of Cape Town (ERC, 2013). They test a domestic carbon tax, a carbon tax plus border tax adjustment (BTA), and a foreign carbon tax for South Africa's main trading partners plus BTA. Carbon tax revenues are recycled into either lower sales taxes, lower capital taxes, or higher social transfers. They find that a phased-in domestic carbon tax which reaches \$30/tCO_2 in 2022 achieves the INDC emissions target. They highlight that the different recycling options have different impacts for income distribution and economic growth.

Our paper aims to provide insights on the interaction between the mitigation objective and the key employment challenge as outlined above. Our analysis makes use of a computable general equilibrium (CGE) model, IMACLIM-SA. Compared to existing literature, our contribution is to combine the strengths of Devarajan et al.'s (2011) efforts to represent market imperfections and Alton et al.'s (2012, 2014) endeavour to link a CGE analysis to the SATIM model (see section 2.1). Besides, we base our modelling on an innovative approach of harmonisation of national accounts and energy balance data, which inter alia allows us to model agent-specific prices of homogeneous goods. Lastly, we contribute to the methodology of modelling skill segmentation of labour, particularly in relation to productivity gains and technical change.

We start this paper with a synthetic presentation of the IMACLIM-SA model complemented with description of its calibration and parameterisation (Section 2). We then discuss how to model the dynamics of labour supply and demand by skill level (Section 3), before heading on to describing our reference projection and scenario outcomes, then focusing on disaggregation of results by skill and household class (Section 4). Lastly, we discuss these results and complement them with some sensitivity analysis and a comparison to findings of others (Section 5), before turning to our conclusion.

2- The IMACLIM-SA model

2-1- Model description

IMACLIM-SA is an open-economy CGE model with 5 energy and 5 non-energy sectors (Table 1); 4 factors of production: capital and 3 labour factors distinguished by the level of skill of the job or the worker (high, medium and low); and 5 household income classes. It is a 'hybrid' of top-down and bottom-up approaches in the sense that it uses electricity production scenarios based on the South Africa TIMES (SATIM) bottom-up model of the energy system (ERC, 2013). IMACLIM-SA has non-perfect markets and non-perfect foresight and makes use of dual and consistent accounting of quantities and values of energy flows within an Input-Output (I-O) table. The model consists of a set of simultaneous, non-linear equations under MS-Excel, which project to 2035, in a single 30-year step, the economy of South Africa at the base year, 2005. We focus the following description on the main features of the model. Schers et al. (2015) propose a complete description including an exhaustive formulary.

2-1-1- Trade-offs in production and international trade

In all sectors except ELC, factor trade-offs in production are modelled using a 'KLEM' production function. Following Van der Werf (2008) we opt for a nested structure combining capital, K, and 3 varieties of labour, L, to form a KL aggregate. Next, KL and an aggregate of energy goods, E, form a KLE aggregate, ultimately traded-off with a 'materials' aggregate, Mat, of non-energy goods and services in the production of domestic output, Y (Figure 1). We use fixed coefficients (Leontief) for the production of both the energy (E) and materials (Mat) aggregate. All other substitution possibilities follow a constant elasticity of substitution (CES) assumption (see Erreur ! Source du renvoi introuvable. in the Appendix for elasticities). For the KL aggregate we assume (i) complementarity between capital K and high-skill labour L3, as suggested by Krusell et al. (2000);[(1)] (ii) substitutability of the resulting KL3 aggregate and medium-skill labour L2 and (iii) substitutability between the KL23 aggregate and low-skill labour L1. Note that contrary to standard CGE models, we do not aggregate profits and fixed capital consumption into capital payments interpreted as the returns to a capital stock, of uncertain measure. Rather, we model profits as mark-ups on total costs and price capital consumption at its renewal cost, i.e. the average price of the investment good (see section 2.1.3 below).

Sector	Full name	Included sectors from SAM 2005
COA	Coal	Coal
OIL	Oil	Oil extraction
GAS	Gas	Gas extraction and distribution
REF	Refineries	Refineries
ELC	Electricity	Electricity
EIN	Energy Intensive Industries	Gold, Other mining, Petrochemical industry, Other non-metallic mineral products, Basic iron/steel, Non-ferrous metals
MAN	Manufacturing	Food, Footwear, Metals basic manufacturing, Electrical machinery, Radio, Transport equipment, Other
LSS	Low-Skill Sectors	Agriculture, Construction, Trade, Hotels & restaurants, Domestic & other services
HSS	High-Skill Services	Water, Communications, Finance, Real estate, Business activities, Government, Health, Social work, Education
TRA	Transport services	Air, water and land freight and passenger transport service

Table 1 Sectors in IMACLIM-SA and corresponding sectors in South Africa's SAM 2005

(1) Krusell et al. have only two types of labour, but our medium- and low-skill categories combined roughly match their unskilled category. Furthermore they distinguish two types of capital: equipment (machines) and infrastructural capital. It is equipment capital that they find high-skill labour to be complementary to, but we simplify, lacking the data to make the same distinction in types of capital.

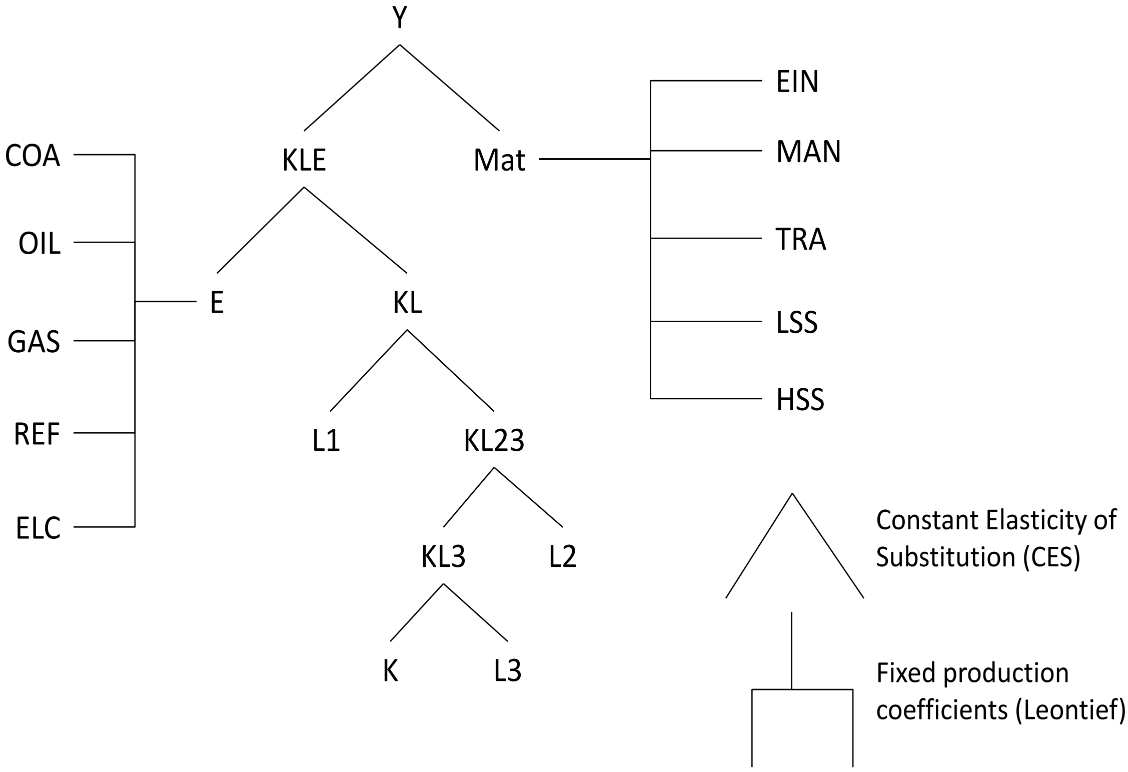

Figure 1 Structure of the nested CES production function

In contrast to other sectors, factor trade-offs in the ELC sector are exogenous, derived from SATIM model runs which incorporate the Updated Integrated Resources Plan for the electricity sector (DoE, 2013) and our carbon tax assumptions. Schers et al. (2015; p.21, pp.71-74) provide more information on the interpretation of SATIM outcomes for IMACLIM-SA inputs.

For all sectors except OIL the ratio of imports to domestic output is elastic to terms-of trade i.e. the ratio of domestic to international prices. Domestic output of the OIL sector is assumed nil. Exports are similarly elastic to terms-of-trade, but around an exogenous trend representing growth of international trade.

2-1-2- Distribution of income and behavioural specifications by agent

Contrary to standard CGE models, which for the sake of simplicity assume households to be the owners of all primary factors, IMACLIM-SA includes detail on the distribution of primary income between households, firms and government: Net wages accrue to households; Gross operating surplus (GOS), including mixed income and imputed rents, is largely allocated to firms but also partly to government and households; Taxes (minus subsidies) on production and social and pension contributions are shared between government and firms. Taxes and social contributions count as income to government. Pension contributions are counted at the same time as an income and as an obligation to households for (financial) firms. IMACLIM-SA furthermore depicts the secondary distribution of income, which consists of a 'debt service' for paying or receiving interests; income, property and other direct tax payments; pensions, unemployment benefits, and other social benefits to households; and a remainder of other transfers between economic agents.

The Gross Disposable Income (GDI) of households fuels consumption and savings following exogenous saving rates slightly raised (Table 2Erreur ! Source du renvoi introuvable.) from the very low 0.1% average of 2005 (StatsSA, 2010b). Investment rates distinct from saving rates are maintained as constant shares of GDI. The difference between savings and investment defines the self-financing capacity (SFC), which accumulates into debt under the assumption of a linear transition of net-of-interest SFC from its 2005 to its projected 2035 balance.

Household class	Class 1	Class 2	Class 3	Class 4	Class 5
Saving rate	0.5%	1.0%	1.0%	2.5%	3.5%

Table 2 2035 saving rates assumptions by household class

Households' consumption trade-offs follow nested-CES specifications (Figure 2; see Table 7 in the Appendix for class-specific elasticities of substitution). However, to account for inertias—e.g. inert housing location determining households' demand for transport—, CES flexibility only applies beyond exogenously set per capita floors to consumption ('basic needs') for electricity, refined products and transport services (in volume). Households' consumption of coal (for cooking and heating) is exogenously set to zero in 2035.

Firms also invest a constant share of their own GDI into gross fixed capital formation. The self-financing capacity of firms, which results from the difference between their GDI and this investment, is thus maintained at its 2005 GDI rate. It accumulates into debt similarly to that of households.

Government both spends and invests constant shares of GDP, rather than of its own specific GDI. The difference with its GDI defines its self-financing capacity, i.e. public deficit, which again accumulates into debt (total public debt) in a manner similar to that of households or firms. In all 2035 projections (except for one scenario) we however constrain public deficit at 2% of GDP by scaling up or down the corporate and household income tax rates.

The above behavioural specifications thus induce a structural surplus for households and a structural deficit for government and firms. At the aggregate national level we assume South Africa to remain a net borrower from the rest of the world (ROW) in 2035, as it was in 2005. This is despite a trade balance surplus, as we will show in section 4, and it results in a reduction in the real exchange rate of the Rand.

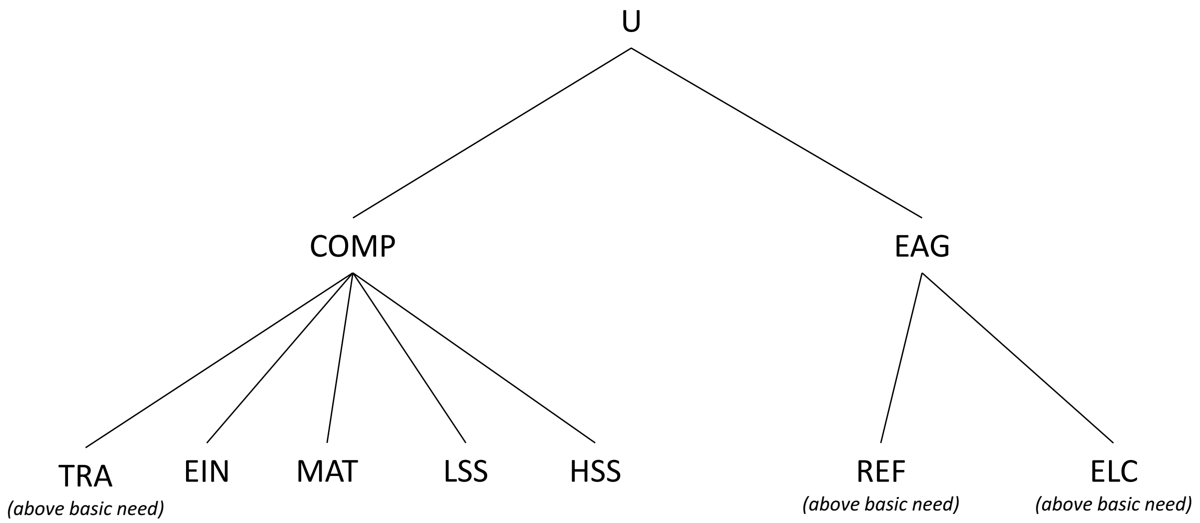

Figure 2 Households' consumption decision tree

2-1-3- Goods, Capital and Labour markets

A few market balances provide the main equilibrium constraints both in the BY and projection year. The first is the balance of the supply and use of all goods: domestic output and imports balance out the sum of intermediate consumption, final consumption (by households and administrations), gross fixed capital formation (investment), and exports.
Secondly, the supply of capital (the sum of all agents' Gross Fixed Capital Formation) and the demand for capital (total consumption of fixed capital by sectors) are linked by a vector of volumes of goods, defining one homogeneous investment good. The vector is set constant at BY values. To balance the capital market, rather than adjusting interest rates, which would impact debt services and thus the GDI of agents and ultimately the investment of households and firms, we adjust the distribution of GOS over firms, households and government.
Lastly, the labour market is segmented in 3 skill markets. In each of these, demand of skill, driven by the intensity in skill of sectors, equals exogenous supply of skill minus unemployment: skill-specific cross-sectoral average wages cannot adjust freely to clear markets because their purchasing power, partially increased with labour productivity gains, are isoelastic to skill-specific unemployment rates via wage curves(2). For each skill, sector-specific wages are set at a constant ratio to the cross-sectoral average wage.

2-2- Model calibration and projection settings

2-2-1- Base Year calibration

We perform Base Year (BY) calibration on a hybrid Input-Output (I-O) table reconciling (i) the monetary I-O table of the Final Social Accounting Matrix (SAM) 2005 (Updated) (StatsSA, 2010b; StatsSA, 2010a), (ii) energy volumes from the Department of Energy (DoE, 2009a) the IEA (IEA, 2012) and the ERC, and (iii) energy prices from several sources (ESKOM, 2005; SAPIA, 2013; NERSA, 2009; DoE, 2009b)(3). For more detail and the final hybrid I-O table and physical balances see Schers et al. (2015; Appendix 2). BY income distribution data also stems from several sources (see StatsSA, 2010b; StatsSA, 2012; SARB, 2007; SARB, 2012).
For the BY composition of the labour force we use numbers of people employed by job type and by educational attainment from the SAM (StatsSA, 2010b). We estimate the unreported job type of the unemployed on the basis of unemployment rates by level of education from the Quarterly Labour Force Survey (QLFS) (StatsSA, 2008). We include "discouraged workseekers" in unemployment numbers, meaning that we report "broad unemployment", at 38.8% in 2005. For total population we use mid-year estimates (StatsSA, 2013), while we draw the size of BY population by age group from UN population prospects (UN, 2013). For the link between job types and skills we follow StatsSA (StatsSA, 2010b. see also Schers et al., 2015; pp.32-34).
Expenditure classes of the SAM 2005 (StatsSA, 2010b) provide data to disaggregate households in 5 social groups at the base year. As the SAM 2005 does not report on the link between household classes and the labour market (job type or level of educational attainment), at the base year we assume a distribution of the unemployed and employed by level of skill, as well as their total net wages, over the 5 household classes (see Schers et al., 2015; Appendix 2).

2-2-2- Prospective demography and distribution of labour income

Prospective population size by age group is drawn from UN population prospects too (UN, 2013). Furthermore, we assume that, for each labour skill, the distribution of active workers over the 5 household classes remains the same in 2035 as it was in 2005 (see Schers et al., 2015; p.36). To calculate the projection year's labour income by skill and household class we calculate the theoretical revenue of each household class on the basis of 2005 wages and the 2035 number of people employed at each skill level. We apply the split among classes of this theoretical total labour income to the effective total labour income taking account of wage and employment shifts.

2-2-3- Productivity and international trade trends

In IMACLIM-SA, besides from demographic changes, economic growth follows from productivity improvements and growth of international trade. In all our scenarios productivity improvements of 2%, 1% and 0.25% per year respectively decrease the capital, labour (for all 3 skills indistinctly) and 'material' (non-energy goods and services) intensities of all sectors alike.
Similarly, a trend increase of export volumes of 1.5% a year benefits all scenarios. It reflects economic growth in South African export markets independent of terms-of-trade variations—which still affect how exports ultimately diverge from the trend.

(2)For all 3 skills we set the elasticity of the wage curve at 0.2. We also consider that a fraction only of labour productivity gains accrues to workers, depending on negotiation position. We thus assume high/medium/low-skill workers to obtain wage increases of 33%/50%/75% of labour productivity gains (at constant unemployment).

(3)For obtaining the majority of this data we are grateful to Bruno Merven and his colleagues of the energy modelling team of the Energy Research Centre at the University of Cape Town.

3 - Dynamics of skill differentiation

Our initial treatment of skills dynamics was to consider that skills are defined by educational attainment and to consequently translate assumed educational improvements into skill supply shifts (see Schers et al., 2015; sections 5.2.1 and 6.1 to 6.2). Implemented in IMACLIM-SA under our central set of assumptions, this 'constant educational attainment' (CEA) approach induced a 7-point decrease of aggregate unemployment by 2035[4],which however masked a large drop of low-skill unemployment (-20 pct. points) and some reduction of medium-skill unemployment (-7 pct. points), in sharp contrast to a slight increase of high-skill unemployment (+1 pct. point). As a consequence, in 2035 the unemployment rate of high-skill labour turned out higher than that of low-skill labour. Such a result is at odds with South Africa's persisting shortage of high-skill labour, and, to the best of our knowledge, contradicts historical developments for the majority of regions around the world. The expectation of a modernizing economy thus seems to conflict with some of our assumptions about labour demand, labour market-clearing, and the CEA approach to skill dynamics. This led us to recognise three possible avenues of improving our modelling of supply and demand of labour disaggregated by level of skill.

We could first change our view of the dynamics of skill supply. The CEA approach can be summarised as representing the view that firms look for sets of skills that are identically linked to educational attainment in 2005 and in 2035. The opposite approach is to consider that what matters for firms is the relative, not the absolute level of educational attainment of individuals. There is indeed some evidence that education has become increasingly "positional" over time (see e.g. Bol, 2015). A simple way to model this second approach is to define skill segmentation as a constant split of the labour force (CSLF). The share of each skill in total labour supply is still calibrated on educational attainment at the base year, but is then kept constant in projection, irrespective of how educational attainment evolves.

A second way of increasing pressure on the high skill market would be to boost high-skill demand by playing on goods-specific income elasticities of consumption. One rationale for this is to consider that richer people tend to spend a higher share of their income on goods and services other than basic needs, of comparatively greater high-skill intensity. It is however unclear if such a preconception is supported by statistics. Anyway it does not show in our limited sectoral disaggregation, where our High-Skill Services sector turns out to have an intensity in high-skill workers per Rand of output 8% below that of our Low-Skill Sectors aggregate.

A third and last way of increasing pressure on the high-skill market would be to differentiate labour productivity gains by skill. As mentioned before, we postulate a uniform 1%-a-year labour productivity improvement across skills and sectors. These gains amount to an exogenous trend forced upon the labour intensity of sectors, all other things (relative prices) remaining equal. They could reflect technological progress, but also progress in educational attainment and otherwise experience-related gains in skill of the labour force. In regard of the huge educational gains and aging of the South African work force it is possible that productivity gains differentiated by labour market skill segment could be more realisitic. Besides, beyond sheer productivity gains, we could consider composition or quality effects to translate into an exogenous increase of high skill-intensity for some sectors. For example, shifting from producing basic equipment to producing technically complex equipment could require higher engineering costs in manufacturing industries (composition effect). Similarly, better enforcement of building regulations could require more consultancy work in building companies (quality effect).

Taking a step back, it appears that the issue we face stems from the heterogeneity of skills and products modelled in 2005 versus their counterparts 30 years ahead. In the abstract framework of CGE modelling, both heterogeneities hide behind nomenclatures common to 2005 and 2035. From this perspective, all suggested alternatives allow a similar acknowledgment of the hidden heterogeneities through a changed definition of either the skills themselves, their use in production, or the complex nature of systems (or technologies) of production that use them. It is thus probable that either of these alternative approaches to skill segmentation could lead to similar projections, if properly calibrated.

For the present study we decide to focus on the most straightforward (if not most explicit) treatment of skill segmentation dynamics: we retain the positional interpretation of skills by defining their supply as constant shares of the labour force (CSLF approach).

(4) For illustrative purposes we ran this CEA approach under the exact same set of parameters as that of our eventual reference projection, notwithstanding the double-counting of productivity improvements entailed by assuming both a general labour productivity increase and an upward shift of skill segmentation.

4 - Modelling results

4-1- Reference Projection

The reference projection (RP) combines the above assumptions and parameterisation in the absence of a carbon tax. It results in real[5] per capita GDP growing from ZAR05 33k in 2005 to ZAR05 71k in 2035, a +116% increase (Figure 3). The obtained 2035 income equals approximately 13k USD13 per capita, equivalent to present-day GDP per capita of Poland. Total GDP grows 2.7 times compared to 2005. Unemployment decreases from 38.8% in 2005 to 28.7% in 2035, whereas CO2 emissions increase by a factor of ca. 1.8 from 443 to 801 Mt, i.e., from 9.3 to 13.5 tonne CO2 (tCO2) annual per capita emissions.
The total number of jobs in RP is 56% higher than in 2005, to be compared with a 34% larger active population. The distribution of this gain across sectors largely follows their output growth in volumes, which is highest for energy-intensive industries (EIN, +186%) and lowest for transport services (TRA, +92%). The diverging trends in output growth reflect different impacts of changes in relative prices on sectoral cost structures, as well as different price elasticities for final consumption and international trade. Typically, LSS and HSS sectors benefit more than other sectors from labour and capital productivity gains due to a combination of high elasticities of substitution between the KL aggregate and intermediate inputs, and a higher cost share of VA (labour and capital).

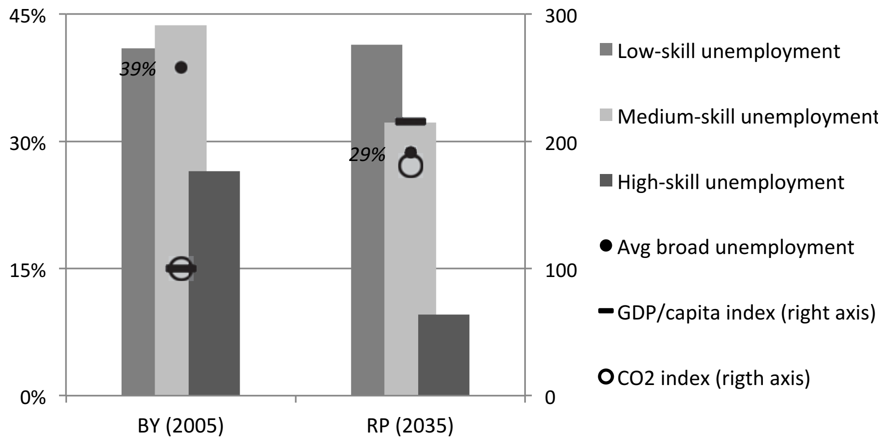

Figure 3 Main performance indicators, base year (BY) and reference projection (RP)

On the expenditure side of GDP the share of the trade balance increases, whereas that of investment decreases (Figure 4). As we have hinted before, domestic prices are substantially scaled down relative to international prices, allowing the trade balance to increase to a positive 5% contribution to GDP. Barring changes in official reserves, this means a need for foreign investment, something which is implied also by our assumption about a continued combined net deficit position of all domestic economic agents. At the sectoral level, imports consequently grow substantially slower than domestic production (2.5 to 3 times slower for EIN, MAN and HSS goods), with the exception of LSS and TRA goods, which are characterised by a low price elasticity of their imported shares. Similarly, thanks to the decrease in domestic prices relative to international prices, exports increase their share in total uses for EIN and MAN products, and to a lesser extent also for HSS and LSS sectors (which have lower export price elasticities; see Table 8 in the Appendix).

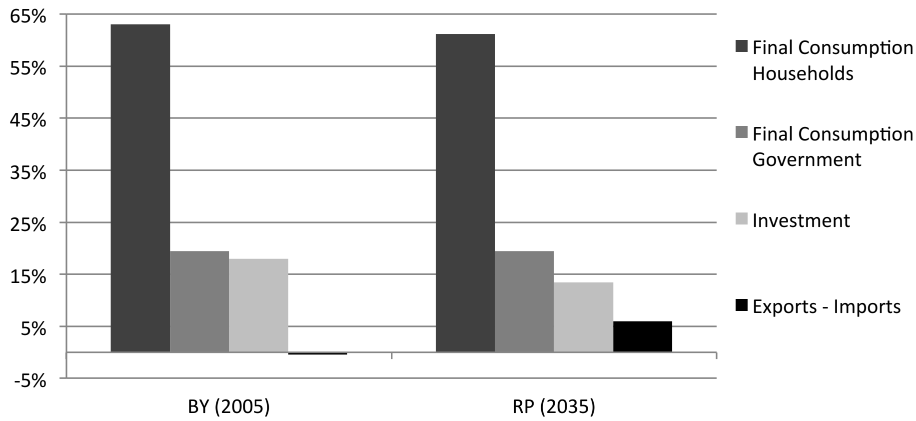

Figure 4 Share of expenditures in total GDP, in Base Year and Reference Projection

Finally, our RP benefitting industries, mining and manufacturing explains the close-to-50% growth of per capita carbon intensity of GDP, as energy sectors (COA, GAS, REF), industries and other mining (EIN) and manufacturing (MAN) account for 59% of CO2 emissions in the BY either directly, or indirectly by their share in electricity consumption (excluding their share in transport services). In 2035 their combined share has grown to 68% of total CO2 emissions.

(5) Per capita GDP corrected for Fisher GDP price indexation.

4-2- Policy scenarios

Our policy scenarios consider carbon taxes of 100 ZAR05/tCO2 and 300 ZAR05/tCO2, i.e. tax levels of ZAR_{13} 170 and 510, or USD_{2013} 18 and 55[6]. These rates are higher than the carbon tax expected to come into force in 2017 (120 ZAR17/tCO2, with sectoral exemptions between 60% and 95%, see RSA, 2015). But, we remain close to the level of the carbon tax in the consulted scenarios of SATIM, and we anticipate on a gradual increase of the carbon tax over time. The ex-ante induced effect on 2035 RP prices differs strongly by fuel (Table 3). Coal is the only domestically produced fossil fuel. Compared to its low domestic price the carbon tax has a strong impact[7]. Conversely, refined products are subject to a pre-existing fuel levy that buffers the impact of the tax.

Table 3 Ex-ante price impacts of carbon taxes on energy products

Carbon tax rate	Coal (COA) price	Oil (OIL) price	Gas (GAS) prices	Refinery products (REF) prices
100 ZAR05/tCO2	+194% (GAS, REF) to +256% (other)	+0.1%*	+4.5% (HSS) to +10.3% (EIN)	+2.8% (HHs) to +3.9% (HSS)
300 ZAR05/tCO2	+583% (GAS, REF) to +768% (other)	+0.2%*	+13.4% (HSS) to +30.9% (EIN)	+8.5% (HHs) to +11.7% (HSS)

*Note: * The tax impacts crude oil prices only via the process losses in refining.*

The differences between scenarios lie in the recycling of tax proceeds. We explore the options of reducing public deficits (possibly leading to a budget surplus) (RDEF), sales taxes (RVAT)[8], or income and corporate taxes (RREV), and of increasing government expenditure (REXP) and transferring proceeds to households on a lump-sum per capita basis (RSUM). All options except RDEF comply with budget neutrality interpreted in the particular sense of a public deficit maintained at the level of 2% of GDP, as targeted in RP, via adjustment of corporate and income tax rates.

All scenarios except RVAT have comparable outcomes in terms of growth, employment and carbon emissions (Table 4). For a 100 ZAR05/tCO2 tax the RDEF, RREV, REXP and RSUM scenarios register, compared to BY, GDP/capita increases between +100% and +105%; unemployment reductions between 6 and 11 percentage points (pct. points); and increases of CO2 emissions between 36% and 39%. The RVAT scenario stands out though, with a GDP per capita increase of +118% and an unemployment reduction of 13.7 pct. points. RVAT thus roughly equals or outperforms RP in terms of GDP and employment, while inducing a substantial (20%) reduction of CO2 emissions. However, this 20% reduction is, like the slightly higher reductions of other scenarios, well below the 2025 pledge of -42% CO2 emissions compared to BAU (Janoska, 2014). A ZAR05 300/tCO2 tax only achieves a 42% to 46% emission reduction in 2035 for the tested scenarios, thus presumably falling short of South Africa's INDC of a 42% reduction in 2025. At this higher carbon tax level the economic performance of RVAT remains better than that of other scenarios. It still outperforms RP in terms of unemployment, although at slightly lower per capita GDP.

In all policy scenarios, employment systematically grows between 2005 and 2035 for all sectors, including the energy sectors. The introduction of a carbon tax causes a small shift in the distribution of employment away from energy sectors (COA, GAS, REF, ELC) and energy intensive industries (EIN), towards High Skill Services (HSS). The manufacturing sector (MAN) remains largely unaffected by the carbon tax. The shift of employment towards the HSS sector is also mirrored by the relative growth in volumes of output. Specifically, at a carbon tax of 100 ZAR05/tCO2 domestic outputs (Y) of the MAN, HSS, LSS and TRA sectors increase more under RVAT than under RP. Conversely, outputs of the energy sectors and EIN increase more under RP than under RVAT. Expectedly, imports of most products register slight increases under the carbon tax regime compared to RP.

Another part of the explanation of the main outcomes of scenarios lies in changes in factor intensities. Labour intensities go down less in the RVAT scenario compared to RP, and also compared to, for instance, RSUM. Labour, as a factor, is necessarily more attractive under a carbon tax regime, with its output coming at a relatively lower cost. One important reason lies in the consumer price indexing of wages, which is directly impacted by the sales tax cut of RVAT while it is not specifically touched by other recycling options.

(6)We use a conversion rate of 6.36ZAR05 to USD05 and for USD05 to USD13 a GDP deflator of 0.861.

(7)We overestimate the price effect on coal by treating domestic coal as exported coal, whereas its energy content is 1/3rd lower. The ex-ante price impact of the carbon tax would be 1/3rd lower too.

(8)For the sake of simplicity IMACLIM-SA models VAT proceeds as if they were sales tax proceeds.

	BY (2005)	RP (2035)	RDEF (2035)	RVAT (2035)	RREV (2035)	REXP (2035)	RSUM (2035)
Results for a CO_2 tax of 100 ZAR05/tonne CO_2							
GDP/capita (ZAR05)	33k	72k	66k	72k	66k	68k	66k
Change vs. BY	-	+116%	+100%	+118%	+101%	+105%	+101%
Unemployment	38.8%	28.7%	32.6%	25.1%	31.4%	28.0%	31.6%
Change vs. BY	-	-11.1pt	-6.2pt	-13.7pt	-7.4pt	-10.8pt	-7.2pt
CO_2 emissions (Mt)	443	801	604	644	610	615	610
Change vs. BY	-	+81%	+36%	+45%	+38%	+39%	+38%
Change vs. RP	-	-	-25%	-20%	-24%	-23%	-24%
Results for a CO_2 tax of 300 ZAR05/tonne CO_2							
GDP/capita (ZAR05)			n/a	69k	n/a	63k	60k
Change vs. BY				+109%		+91%	+83%
Unemployment				26.2%		30.7%	35.6%
Change vs. BY				-12.8pt		-8.1pt	-3.2pt
CO_2 emissions (Mt)				467		434	428
Change vs. BY				+5%		-2%	-3%
Change vs. RP				-42%		-46%	-46%

Table 4 Main base year statistics and RP and scenario outcomes

4-3- Results by skill and class

Our RP displays an absolute increase in employment for all skill levels, but growth is stronger for high- and medium-skill labour (Table 5). In Schers et al. (2015) we report the changes in employment for the RP by sector and by skill level. Those numbers show that it is mainly the LSS sector, and to a lesser extent HSS, EIN and MAN, that contribute to growth of medium-skill employment. Growth in high-skill employment mainly takes place in the HSS sector, but is fastest in EIN and in ELC (as derived from SATIM, see section 0). Growth in low-skill employment is almost entirely located in LSS. From this we conclude that structural change (from LSS to HSS, EIN and MAN) only partly explains the shift in jobs by skill level; changes in relative prices and productivity add to the shift of employment towards high- and medium-skill jobs.

	BY 2005	RP 2035
Total employed (millions)	12.3	19.2
High-skill share	30%	32%
Medium-skill share	47%	49%
Low-skill share	22%	19%

Table 5 Skill split of total employment for the BY and the RP

In terms of income distribution, classes 3 and 4 (which both have per capita gross disposable incomes below national average) register the largest relative increases in income. The reason for this is that classes 3 to 5 all profit comparably from the wage increases caused by growth in employment of especially medium- and high-skill labour. However labour income is a smaller share of class 5's total income, which also substantially consists of capital returns and interest payments and thus does not grow as fast as class 3 or class 4 income.

In comparison to RP, the carbon tax scenarios systematically induce a shift of employment towards high-skill jobs. This reflects the induced shift in sectoral activity away from energy sectors and EIN and towards the HSS sector, which has a higher high-skill intensity.

Per capita real Gross Disposable Income (GDI, after taxes) of household classes evolves differently in the RSUM scenario, which is the only scenario that sees a strong decrease in the ratio of class 5 per capita GDI (highest) over class 1 per capita GDI (lowest), from respectively 41:1 in 2005 to 30:1 in 2035 at a carbon tax rate of 100 ZAR05/tCO2[9]. Already at this lower tax rate a lump-sum transfer (RSUM) clearly benefits the lower income classes, for whom it translates in a much larger share of income before taxes (28%) than for the highest income-earning classes (5% for class 4, 1% for class 5). Conversely, we observe that class 4 households benefit strongest from recycling through sales tax reduction, with their GDI growing 17 percentage points more than in RP. The reason lies in a combination of employment effects (growth in medium- and high-skill employment), wage growth, and consumer price index effects.

(9)Having only five household classes, with classes taken from Statistics South Africa in the BY defined by per household income, does not allow to properly calculate a Gini coefficient.

4-4- Impacts of investment in education

Finally, in an additional 'RVAT+' scenario based on our most economically beneficial RVAT scenario, we explore the possibility to divert part of the carbon tax proceeds to investment in education and training of employees and workseekers. We assume that this investment translates in one million additional high school students relative to our reference demography scenario of constant enrolment, starting in 2015, for a total cost that we estimate at 7.5 billion ZAR05 per year (Schers et al., 2015). This amounts to about 10% of the 2035 proceeds of the 100 ZAR05/tCO2 tax in the RVAT scenario, and to 1.25% (2.5% in BY) of 2035 government expenditure on final consumption and administration in RVAT+ (636 billion ZAR05). Under a Constant Educational Attainment (CEA) approach of skill definition, this increased spending would translate into a downward shift of skill segmentation thresholds. Under our Constant Share of Labour Force (CSLF) definition of skills we rather assume that it positively impacts annual growth of productivity of all four primary factors (capital and 3 labour skills) equally.
However, calibrating the productivity impact of increased educational spending is difficult. Literature offers different visions of the links between education, skill and productivity, but does not seem to provide any statistical correlation between investment in education and educational output (in terms of the number of people with degrees). Grigoli (2014), for instance, points to the "inefficiency" of educational spending on secondary education enrolment. Quality of education should also impact how labour productivity benefits educational attainment, but lacks objective measurement and is even harder to connect to investment. Our analysis is thus exploratory, in the sense that (i) it postulates increased enrolment and adds up the estimate consecutive educational cost to public expenditure, but does not really settle on how one million additional students are drawn to high schools; (ii) for lack of any estimate on how high school enrolment ultimately benefits productivity, it limits itself to revealing what productivity impact is required to make the educational investment a profitable option, in GDP terms, in the modelling framework of IMACLIM-SA.
At 100 ZAR05/tCO2, the threshold over which RVAT+ induces a higher GDP trajectory than RVAT turns out to be a modest 1% increase of annual productivity gains (Schers et al., 2015). We view this as a confirmation that education and training expenses could be a relevant option for carbon tax recycling in the South African context. It must be noted, however, that the equivalent GDP performance comes at some slight employment cost (-0.15 pct points). Besides, this cost masks an increase of high-skill employment at the cost of a decrease of low-skill employment. This follows from the combined impact of capital and labour productivity gains, which in our nested-CES structure benefits high-skill labour.

5- Discussion and sensitivity analysis

5-1- General discussion

Our analysis only covered a certain set of policies, and for instance did not test the impact of reducing taxes on capital, or sales tax cuts differentiated by type of product. Recycling carbon tax proceeds in lower VAT is thus only the better of the 5 recycling options explored. Besides, our numerical results are conditional on our methodological choices. Specifically, our assumption of a wage curve linking real wage and unemployment gives the sales tax recycling option a specific deflationary impact (in real terms), via consumer price indexation. This assumption is thus central to our findings. Another limitation of our scenarios is that we did not account for any socio-economic benefits of increased public spending (REXP scenario) or of a lump-sum transfer (RSUM) on productivity (e.g. from better public care or a reduction in crime)[10].
As regards investment in skills through education or training, our assumed link between investment and productivity remains hypothetical. More specific research should be consulted to find out what type of interventions lead to productivity improvements. Our experiments also point to the need to better understand the interplay of technological change and skill supply and demand. In our sensitivity analysis (see below) we show that there is a need to design interventions regarding education and training of the low-skill segments of the labour market in such a way that their skills become more compatible with technological development.

(10) Although questioned, such benefits are supported by e.g. the evaluation of a basic income trial in Namibia by Haarmann et al. (2009), and by an evaluation of the Mincome project by Forget (2011).

5-2 - Sensitivity analysis of reference projection parameterisation

We performed a sensitivity analysis on the parameterisation of the RP around different groups of parameters (for details see Schers et al., 2015). Expectedly, the main exogenous drivers of economic growth in IMACLIM-SA (namely the export volume trends and labour and capital productivity gains) have a strong impact on real GDP. The elasticity common to the 3 wage curves governing skill markets is another key parameter. A more rigid response of wages to unemployment reduction keeps costs and prices low and favours domestic output and hence economic growth. A third set of influential parameters are the elasticities of substitution of skills to capital and capital-labour aggregates (see section 0). Labour demand rigidity has little effect on economic growth, but an interesting impact on employment by skill: Lower elasticities benefit medium- and low-skill labour, as they become more complementary to capital. Finally, increased price elasticities of both exports and imports lead to significantly more economic growth. This gain is explained by our RP computing a South African Rand, i.e. a favourable evolution of terms-of-trade that has a bigger impact when trade elasticities are high.

5-3- Comparison of model outcome with other analyses

The present study is closest to Alton et al. (2012), who find that a carbon tax of Rand 210/tCO2 leads in 2025 to a 42% decrease in GHG emissions relative to BAU—i.e., is consistent with South Africa objectives—, and with GDP loss in 2025 between 0.68% and 1.23% relative to BAU, depending on recycling option. Thus, Alton et al. also find that the South African economy is very responsive to seemingly modest rates of a carbon tax, notably because of low starting point prices of energy (as also outlined e.g. in Pauw, 2007, Table 6 p.35). On the other hand, they find a narrower range of impacts of a carbon tax on GDP than our own findings, all the more so as in their study GDP is growing at 3.9% per annum over 2010-2025 (against 3.4% per annum over the 2005-2035 period in our RP)[(11)]. This may be caused by all their recycling schemes including 'border tax adjustment', i.e. a tax on imports and a rebate on exports on top of the domestic carbon tax.

Van Heerden et al. (2006) also obtain strong impacts of limited carbon taxes on South African emissions. Particularly, they find a strong triple dividend—i.e., an increase in GDP and reduction in poverty and CO2 emissions—when recycling carbon tax revenues in food tax breaks. The mechanism, they contend, is that "when energy is complementary to capital [as they assume], and when tax revenue recycling can be used to increase unskilled labour demand [as the food tax break does by increasing demand for agricultural products and thus for agricultural, mostly low-skilled labour], a double dividend may materialize in South Africa as in the model of Bovenberg and Van der Ploeg (1996, 1998)." We do not test a similar recycling mechanism, but the results would likely be different because in our model energy and the capital-labour aggregate can be substitutes. Furthermore, our wage curve limits the increase in demand for unskilled labour by having it raise wages.

Turning to the numerous studies on other countries, we emphasize that our findings echo the IPCC synthesis of the institution's 2001 report (IPCC, 2001): Any given economy's most efficient recycling option is that of reducing its most distortionary pre-existing tax. Faced with the South African economic and social context, IMACLIM-SA purposely lends great importance to imperfect segmented labour markets where wages cannot freely adjust to absorb labour supply because they are also required to preserve purchasing power. It is a consequence of this central second-best feature of our model that the most efficient recycling option turns out to be that which best preserves purchasing power, namely the reduction of sales taxes.

(11) We find GDP losses for a ZAR05 300/tCO2 tax in the RVAT scenario around 3%, or approximately one year of GDP growth, relative to RP in 2035, and higher (-10% and -16%) for other scenarios.

6- Conclusion

In this paper we analyse how climate mitigation interacts with economic growth and unemployment reduction in South Africa under various policy options for recycling the revenues of a carbon tax. We find that a relatively low tax level (100 ZAR05/tCO2) may positively impact South Africa's economic perspectives in terms of GDP and employment provided that tax revenues are used to reduce sales taxes. A sales tax reduction leads to economic benefits by moderating real wage increases via consumer price indexation. Other recycling schemes do not yield such a double dividend. However, a higher carbon tax (300 ZAR2005/tCO2 or higher) is needed to achieve South Africa's mitigation commitment. At this higher carbon tax level, the sales tax reduction remains the best recycling option, resulting in a maintained unemployment gain, although at a small GDP cost. At both the lower and higher tax levels, lump-sum transfers of carbon tax proceeds to households on a per capita basis are the only option that reduces inequalities relative to the reference projection, but perform poorly in efficiency terms.

We also tested the possibility of using a part of carbon tax proceeds to invest in education and training with the goal of improving productivity. In our model an investment of 7.5 million ZAR05 annually or 10% of the proceeds of a tax of 100 ZAR05/tCO2, covering the cost of one million additional high-school students per year, would only need to increase productivity growth by 1% per year to lead to a higher GDP than when recycling all proceeds into a reduction of sales taxes. The downside is that the overall productivity increase in this scenario would increase inequality between high skill and low skill labour.

Methodologically, modelling supply and demand of labour by level of skill in a CGE-style model turned out to require careful consideration. Skill supply dynamics greatly differ whether skills are considered absolute abilities attached to educational degree or relative capacities on labour markets where educational achievement is increasingly positional. Skill demand dynamics raise additional questions on what assumptions to make about biased technical change (contrasted skill intensity evolutions) or the dynamics of consumer preferences. These are important, unsettled questions that will require further research. Our modelling runs nonetheless confirm the potential interest of recycling carbon tax revenues into education and training, but also that ways to improve complementarity of low and medium skill labour with technological development should be investigated.

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Appendices

Table 6 Nested-CES production function elasticities of IMACLIM-SA sectors

Sector*	KLE to Mat	KL to E	KL23 to L1	KL3 to L2	K to L3
COA	0.1	0.25	4	1.5	0.1
GAS	0.1	0.25	4	1.5	0.1
REF	0.1	0.2	4	1.5	0.1
ELC	0.1	0.2	4	1.5	0.1
EIN	0.1	0.25	4	1.5	0.1
MAN	0.1	0.64	4	1.5	0.1
LSS	0.1	0.64	4	1.5	0.1
HSS	0.1	0.99	4	1.5	0.1
TRA	0.1	0.18	4	1.5	0.1

*Note: * We report no estimates for the OIL sector, whose output is systematically projected nil in 2035.*

Table 7 Assumed nested-CES household consumption elasticities of IMACLIM-SA

Household class	Class 1	Class 2	Class 3	Class 4	Class 5
Elasticity of substitution of EAG, COMP in U	0.5	0.5	0.5	0.5	0.5
Elasticity of substitution of ELC, REF in EAG	0.5	0.4	0.3	0.2	0.1
Elasticity of substitution of EIN, MAN, LSS, HSS, TRA in COMP	1.5	1.5	1.5	1.5	1.5

Table 8 Terms-of-trade elasticities of exports and imports of IMACLIM-SA

Sector	COA	OIL	GAS	REF	ELC	EIN	MAN	LSS	HSS	TRA
σ_{Mp}	0.50	0.10	0.50	0.75	0.25	1.00	1.00	0.10	0.75	0.10
σ_{Xp}	1.00	0.10	0.10	0.75	0.10	1.00	1.00	0.10	0.75	0.10

Note: σ_{Mp} is elasticity to terms-of-trade of share of imports in total resource (volume), σ_{Xp} is the elasticity to terms-of-trade of sheer exports.

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