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The implications of national and international carbon-pricing policies for the South African Reserve Bank

Luca Deidda[*] and Laurence Harris[†]

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Abstract

This paper addresses the implications for the South African Reserve Bank (SARB) of climate change mitigation measures undertaken by foreign countries. We focus in particular on the implications of these measures for the SARB's responsibility to maintain financial stability and manage monetary policy. Carbon pricing is central to both current and projected international mitigation measures. An important instrument other countries can use to support carbon pricing without diminishing their international competitiveness is a carbon border tax applied to imports from countries with a low carbon price and high carbon intensity of production. In this paper, we show that South Africa's carbon tax system currently imposes a carbon price much lower than that of its major trading partners such as the European Union (EU). At the same time, the carbon intensity of South Africa's gross domestic product is high by international standards, and the carbon intensity of its tradables is higher than that of its main trading partners. As a result, South Africa's potential sensitivity to other countries' high carbon border taxes, such as those envisaged under the EU's European Green Deal. This paper outlines the implications of carbon border taxes for the SARB's financial stability policy and monetary policy.

JEL classification: E44, E58, F13, 055, Q54

Keywords: Central banking, carbon price, carbon border tax, financial stability, monetary policy

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1. Introduction[1]

This paper addresses the implications for the SARB of climate change mitigation measures undertaken by foreign countries. International mitigation measures, both current and projected, have carbon pricing at their centre. An important instrument other countries can use to support carbon pricing without diminishing their international competitiveness is a carbon border tax at a rate that is higher for countries with low carbon prices and high carbon intensity of production.

South Africa's carbon tax system currently imposes a carbon price much lower than that of its major trading partners such as the EU. At the same time, the carbon intensity of South Africa's GDP is high by international standards, and the carbon intensity of its tradables is higher than that of its main trading partners. South Africa is effectively a net exporter of carbon, and the gap between its emissions and its current trading partners makes it susceptible to high carbon border taxes. We examine the implications for SARB's financial stability responsibility and for its monetary policy framework.

1.1 Global trends

The significance of the issues is indicated by the implementation to date of international carbon-pricing mechanisms such as carbon taxes and emission trading systems (ETSs). As of April 2021, 64 carbon-pricing mechanisms were in operation, yet the extent of implementation of national and regional policies varies considerably across the world, as shown in Box 1.

Box 1: CO2 pricing policies around the world

Asia

China's ETS in January 2021 covered 30% of national emissions. Kazakhstan has an ETS covering 43% of national emissions; price: US$1 per ton of carbon dioxide equivalent (tCO2). The Republic of Korea implemented its ETS in 2015, covering 74% of its national emissions; price: US$17 per ton of carbon dioxide equivalent (tCO2e). Japan has had a carbon tax since 2012 and it covers 75% of national emissions; price: US$3/tCO2e. Indonesia, Pakistan, Sakhalin, Vietnam and Thailand have ETS programmes under consideration.

1 This research was undertaken with the support of the International Food Policy Research Institute, the European Union (EU) and Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH.

Africa

South Africa has had a carbon tax in place since 2019; price: US$9/tCO2e. No other African country has implemented any carbon-pricing mechanism thus far. Côte d'Ivoire and Senegal are considering it.

Europe

In 2005, the 27 EU countries, plus Liechtenstein, Iceland and Norway implemented an international ETS. It covers 39% of the area's emissions; price: US$50/tCO2e. Various EU members have implemented or intend to implement national policies. Germany introduced its own ETS in 2021, which covers heat and road transport sectors currently not covered by the EU ETS; price: US$29/tCO2e, which is expected to increase to US$65/tCO2e in 2025. Poland established a carbon tax in 1990, which covers 0.04% of national emissions; price: US$0.08/tCO2e. Austria is considering developing a national ETS to cover transportation and buildings, which are not covered by the EU ETS. Sweden introduced a carbon tax in 1991, covering 40% of national emissions; price: US$137/tCO2e. Finland introduced a carbon tax in 1990, covering 36% of national emissions; price: US$72.8/tCO2 for transport fuels and US$62.3/tCO2 on fossil fuels for other uses. Denmark introduced an ETS in 1992, covering 35% of national emissions; price: US$28/tCO2 for fossil fuels and US$24/tCO2 for greenhouse gases. France has had a carbon tax since 2014, covering 35% of national emissions; price: US$52/tCO2. Spain has had a carbon tax since 2014, covering 3% of national emissions; price: US$18/tCO2. Ireland implemented a carbon tax in 2010, covering 49% of emissions (all types of fuels); price: US$39/tCO2e. Iceland and Norway, which adhere to the EU ETS, established carbon taxes in 2010 and 2017, respectively. In Iceland, the tax covers 55% of national emissions; the price for fossil fuels is US$35/tCO2e and for greenhouse gas is US$20/tCO2e. In Norway, the carbon price is US$53/tCO2e. The UK has two policies in place: an ETS was established in 2021, as the country had opted out of the EU, and a carbon tax of US$25/tCO2e covers 23% of emissions.

North America

Canada has had a federal ETS and a federal carbon tax in place since 2019, covering 9% and 22% of national emissions, respectively; price: US$32/tCO2. Within Canada, states have implemented or intend to implement national policies. Alberta has had an ETS since 2007, covering 56% of emissions; price: US$32/tCO2e. British Columbia has an ETS that will apply to liquefied natural gas facilities once they become active, and has had a carbon tax since 2008 that covers 78% of emissions; price: US$36/tCO2e. The Northwestern territories have a carbon tax covering 79% of national emissions; the price is aligned to the federal one and is expected to increase to US$40/tCO2e in 2022. Saskatchewan has had an ETS since 2019, covering 11% of emissions; price: US$32/tCO2. Manitoba is considering both a national ETS and a carbon tax. Quebec has had an ETS since 2013, covering 78% of national emissions; price: US$18/tCO2e. Nova Scotia has had an ETS since 2013, covering 80% of emissions; price: US$20/tCO2. Newfoundland and Labrador have had an ETS since 2019, covering 43% of emissions, with a carbon tax covering 47% of emissions; price: US$24/tCO2. The Prince Edward Islands have had a carbon tax since 2019, covering 56% of emissions; price: US$24/tCO2.

The US does not have an active federal carbon policy. Various individual states have one. Massachusetts has an ETS since 2018 covering 16% of emissions; price: US$6.5/tCO2e. California has had an ETS since 2012, covering 80% of emissions; price: US$18/tCO2e.

Pennsylvania and Oregon are considering introducing an ETS. Washington state also launched one in 2017, which is expected to cover 67% of emissions if operative.

South America

Mexico introduced a federal carbon tax in 2014. It covers 23% of emissions and its price is US$3/tCO2e. Mexico also started a two-stage process to implement an ETS that would cover 40% of emissions. Within Mexico, Tamaulipas started a carbon tax in 2021, with a price of US$13/tCO2e, after Baja California introduced its carbon tax in 2020 with a price of US$8/tCO2e. Zacatecas has had a carbon tax since 2017, with a price of US$8/tCO2e. Jalisco is currently considering introducing a carbon tax. Colombia has had a carbon tax covering 24% of emissions since 2017, priced at US$5/tCO2e, and is currently considering implementing an ETS. In Brazil, there is an ongoing discussion at the governmental level about introducing a pricing system for carbon, but the country is still undecided. Argentina implemented a carbon tax in 2018, which covers 20% of emissions, with a price of US$6/tCO2e. Chile implemented its carbon tax one year before Argentina, covering 39% of national emissions, at US$5/tCO2e. The implementation of an ETS in Chile is under discussion.

Australia and Oceania

New Zealand implemented its ETS in 2008 and it covers 51% of national emissions, at NZ$76/tCO2e.

Source: World Bank Carbon Pricing Dashboard, https://carbonpricingdashboard.worldbank.org/

Further development of countries' and regions' carbon pricing mechanisms result from agreements reached at the United Nations Framework Convention on Climate Change (UNFCCC) Conference of the Parties 26 (COP26) and prior plans such as the EU's European Green Deal[2] for a comprehensive mitigation strategy from 2019 to 2024. Many countries and international organisations are implementing cross-border pricing equalisation mechanisms, such as carbon border taxes, to prevent carbon leakage caused by companies moving abroad to take advantage of lower carbon prices.[3] The EU's European Green Deal proposes a carbon border adjustment mechanism (carbon border tax) whereby companies importing to the EU goods and services produced in a third country will have to pay the same carbon price they would have paid had the goods being produced in the EU. Conversely, if the non-EU producer of the imported

[2] https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en.

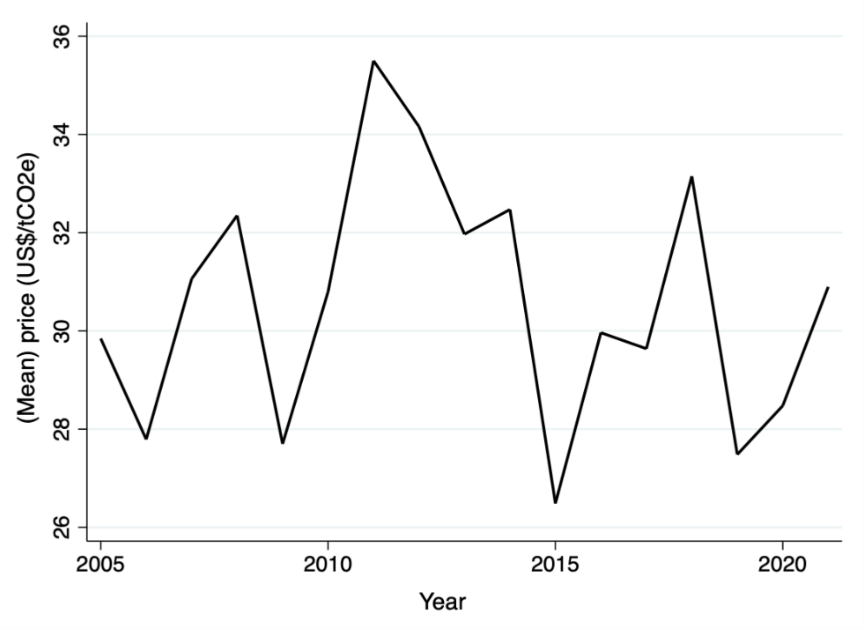
[3] Another two indirect mechanisms lead to carbon leakage. Firstly, as a consequence of the rising prices of CO2 emissions in some countries, the comparative advantage of running carbon-intensive industries would increase the number of less environmentally friendly countries that keep such prices low. Secondly, the shift toward renewable energy sources would reduce the international prices of fossil fuels, putting further pressure on the carbon-intensive industries of countries characterised by low carbon prices. See Cheng and Ishikawa (2021) for a discussion and for bibliographic references.

goods has already paid a sufficiently high price for their emissions in a third country, this cost would be deductible for the correspondent EU importers. This gives non-EU countries an incentive to implement policies to reduce the emissions intensity of their production of tradables.

Despite carbon-pricing policies gaining a primary role in discussions of national and international long-term strategies, there remains substantial cross-country heterogeneity in the adopted measures and the global and regional dispersion of nominal carbon prices. Some continents have barely started implementing carbon-pricing measures; in this respect, it is notable that, aside from South Africa, no African country has implemented an effective carbon policy. Moreover, South Africa's carbon-pricing mechanism, a carbon tax that came into effect in 2019, imposes a much lower price than in its major export markets such as the EU and UK. In its initial phase through 2022, the tax was set at a rate of R127 (US$8.5)/tCO2e (plus inflation-based annual adjustment), and it only applies to a narrow range of emitting activities. The effective tax rate is reduced further by generous tax allowances; it has been estimated that emitters within its scope will be liable to effective rates as low as R6.35–R50.8 (US$0.42–US$3.4) for Phase 1, which runs until the end of 2022 (International Energy Agency 2020). Since major trading partners such as the EU and the UK do have carbon-pricing mechanisms with prices at sustained and substantial positive levels, the exports and capital flows of developing countries without comparable pricing mechanisms will be affected.

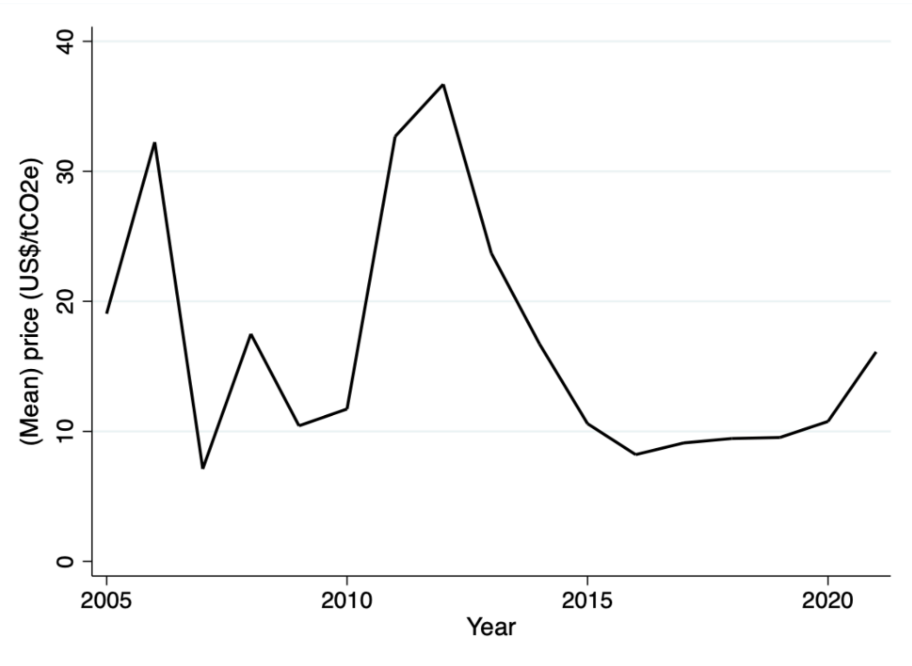
The evolution of national and regional ETSs and carbon taxes translates into heterogeneity in the carbon price obtaining across the world, as shown in Figures 1 to 3. The global average carbon price determined by carbon taxes and carbon markets, as shown in Figures 1 and 2, demonstrates that heterogeneity has been accompanied by significant price variance over time, with no sign of the upward trend that is required in order to induce the carbon-reducing economic change that is the strategic objective of carbon taxes and ETSs. Moreover, when including the zero price of carbon in countries without ETSs or carbon taxes, the world average price of carbon in 2021 is as low as US$3, according to an estimate by the International Monetary Fund (IMF) (Parry, Black and Roaf 2021).

Figure 1: Average world price of CO2 (carbon taxes)



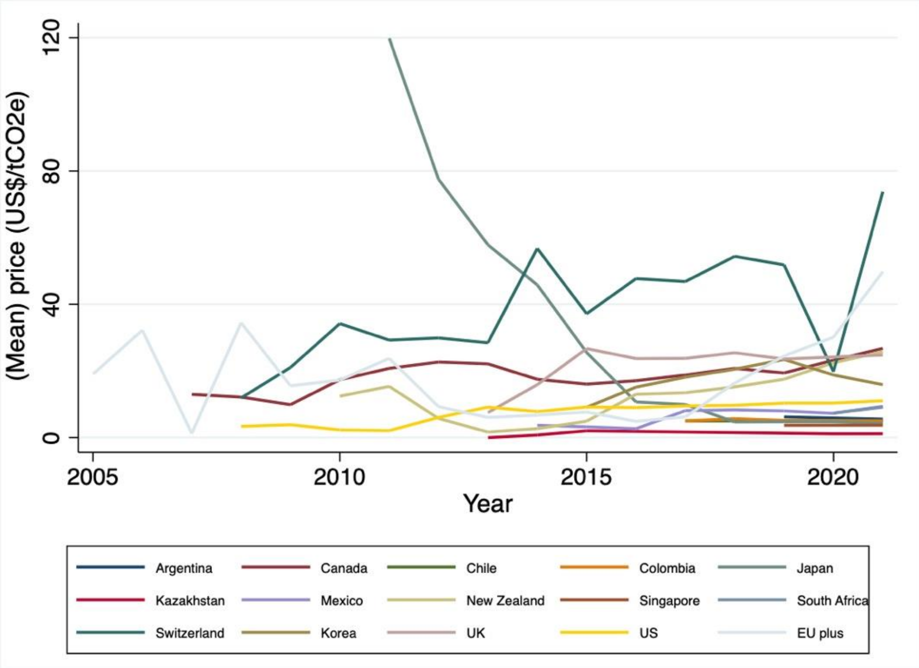
Source: World Bank and the authors

Figure 2: Average world price of CO2 (ETSs)



Source: World Bank and the authors

Figure 3: Distribution of CO2 prices resulting from ETSs and carbon taxes



Source: World Bank and the authors

The heterogeneity of carbon taxes and ETSs and their weak effects on average carbon prices imply that, to achieve the global emission targets agreed within the UNFCCC framework, states (including subnational and supra-national entities) will need to construct more extensive and better-functioning pricing mechanisms and achieve stronger upward trends in carbon pricing. Achieving this through a succession of new national or regional carbon taxes and ETSs, complemented by carbon border taxes, may be inefficient in many ways compared to a strategy for establishing a global carbon price or global price floor, but it is currently the path that is envisaged (Parry, Black and Roaf 2021). Consequently, developing countries like South Africa that do not have sufficiently effective carbon-pricing mechanisms will increasingly face barriers such as carbon border taxes in trade with countries that do. In the medium term, South Africa will face the relatively mature carbon-pricing mechanisms of the EU, a major trading partner.

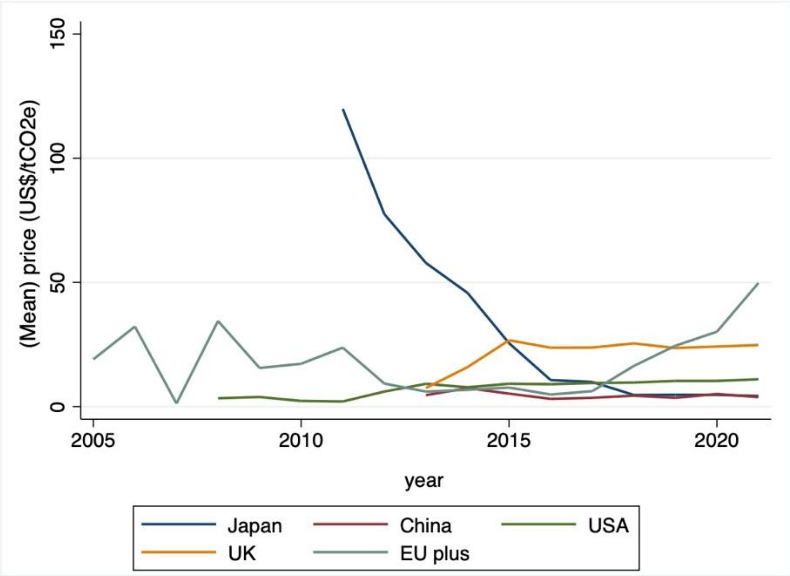
Figures 3 and 4 offer a synthesis of the evolving cross-country distribution of carbon prices under ETSs and carbon taxes respectively. They show that:

1. the number of countries that have implemented carbon-pricing policies has increased over time; and

2. the price of carbon has increased substantially in leading countries (e.g. the UK, the US and China) and regions (e.g. the EU) (see Figure 4).

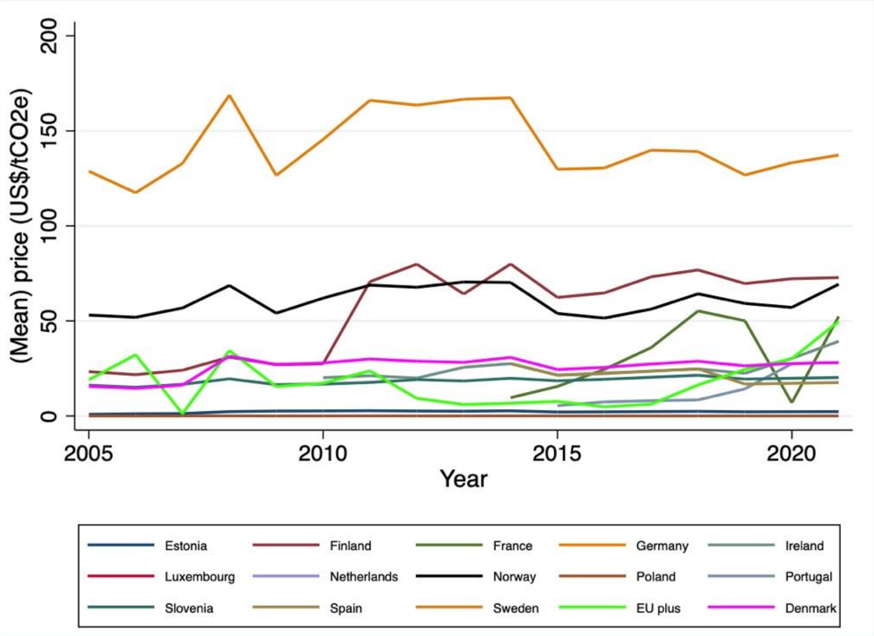
The sustained increase in EU carbon prices since 2018 (EU pricing reached 50 euro/tCO2e in 2021) followed the reform of the EU's ETS in 2018. It has been estimated that the EU carbon price per ton equivalent will be between 85 and 100 euro/tCO2e by 2030, broadly in line with the analysis of the high-level commission on carbon prices chaired by Joseph Stiglitz and Nicola Stern in 2017. These estimates indicate the size of the gap between the carbon price in the EU and South Africa, and therefore the size of a carbon border tax that may be imposed on South African exports.

Figure 4: Distribution of prices of CO2 from ETSs and carbon taxes in a sample of countries



Source: World Bank and the authors

Figure 5: Price of CO2 resulting from national policies within the EU



Source: World Bank and the authors

2. Outline of South Africa's financial sector

South Africa's highly developed financial sector comprises various types of financial intermediaries. The largest categories are banks, insurance companies, pension schemes and collective investment schemes (investment funds of several types). The total assets of the banking sector in 2020 amounted to R6 457 billion (US$441 billion), of which R4 542 billion (US$310 billion) were loans and advances. The high concentration of the country's banking sector is marked by the fact that 90% of banks' assets are held by the five largest banks. The total assets of the insurance sector in 2020 amounted to R3 494 billion (US$238 billion). In this paper, we focus on the banking sector's exposure to risks emanating from international climate policies, specifically the asset risks resulting from their credit exposure.

3. Financial stability

3.1 Transmission routes

Other countries' adoption of climate change mitigation measures will affect many dimensions of South Africa's economy, including trade, production and employment. It will affect the country's financial sector in three ways.

3.1.1 Indirect channel through real economy shocks

The mitigation measures taken by other countries will, by design, affect the trade, production and employment of carbon-heavy sectors in South Africa. As a result, their expected profitability, their debt-service ability, and the economic value of their assets will be impacted negatively (at the extreme, assets will become 'stranded assets'); these sectors' loans and debt held by banks and other financial institutions will, effectively, be impaired.

In this paper, we present our estimates of the size of the links in this indirect channel. We first estimate their effect on the real economy, differentiating sectors according to their carbon intensity and trade exposure. We then consider the exposure of the financial system to the most trade-exposed sectors in order to estimate the effects of foreign carbon pricing and carbon border taxes. While these estimates relate to shocks to industrial sectors in the real economy, the financial sector's exposure to household debt will also be impacted to the extent that workers' earnings and jobs in negatively impacted sectors are likely to decline.

3.1.2 Direct effect

Banks and investment managers across the world are reorienting their financial strategies to actively promote investment in activities supporting 'net-zero' goals. The structural shift in financial markets, presaged by initiatives such as the Glasgow Financial Alliance for Net Zero, which in November 2021 comprised more than 400 financial firms controlling a total of US$130 trillion in assets,[4] can be expected to create shocks in international and national financial markets. Such shocks are independent of South Africa's real economy shocks (South Africa's financial cycle does not coincide with its business cycle)[5] and represent a direct effect of international mitigation, putting the stability of South Africa's financial sector at risk.

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[4] The Glasgow Financial Alliance for Net Zero, 'Our progress and plan towards a net-zero global economy', November 2021. https://assets.bbhub.io/company/sites/63/2021/11/GFANZ-Progress-Report.pdf.

[5] SARB, *Financial Stability Review*, May 2021, Figure 4.

3.1.3 Induced effect

Mitigation policies adopted in other countries, such as carbon border taxes and financial firms' green investment strategies, act as incentives for South African firms themselves to adopt green strategies. Industrial firms are incentivised to adopt low-emission production technologies in order to minimise the effect on their exports of border taxes or similar obstacles to trade. Similarly, the adoption of net-zero strategies by financial firms in other countries incentivises South African financial firms to change their strategies for fear of being locked out of transactions with foreign banks and investors. Transformation to achieve such induced changes in South Africa's financial sector increases the potential for shocks to income and balance sheets and increases the risk to financial stability.

3.2 Policy recommendations

3.2.1 Develop an effective monitoring system

We recommend that the SARB develops a framework for estimating and monitoring the impact of international mitigation policies on South Africa's financial stability. In Section 5 we outline and apply a potential framework. As we note there, a priority for the SARB should be to construct data, disaggregated to individual banks (and non-bank financial firms), on the carbon intensity of firms whose liabilities are held in the banks' asset portfolios. As South Africa's National Treasury notes,[6] the Prudential Authority, which supervises banks under its mandate for microprudential regulation, has not hitherto obtained data on the sustainability of assets currently in its portfolio. The absence of reliable, detailed data on the carbon intensity of portfolios hinders all aspects of policy for greening South Africa's financial sector. In order to apply a sound monitoring framework, such data is essential in order to make the link between shocks to the real economy and risks to financial stability.

More broadly, the monitoring framework, as applied to the indirect transmission channel, will require sound current data on international carbon policies and the resulting carbon prices across countries, especially that of South Africa's key trading partners, and production sectors. The framework will also require data on the evolution

6 'Financing a sustainable economy', National Treasury Technical Paper 2021, Section 5.3.

of the carbon footprint composition by sector of South Africa's economy, with particular attention to crucial import and export sectors that require monitoring.

Assessing the risk exposure of South Africa's economy to the indirect risks of climate change requires measuring the carbon footprint of companies. In turn, this requires building a reporting system. The issue is what and how to report. Reporting systems are already in place, and data management companies assemble these raw data and estimate the emissions of companies that fail to submit reports. Aggregation is based on a standard Greenhouse Gas Protocol classification that comprises direct emissions, emissions from electricity usage, and indirect emissions from upstream and downstream supply chains.

We note that at a global level, reporting companies are still a tiny minority. Only 15% of listed companies around the world report their emissions. The fraction of reporting companies among those that are privately owned is even smaller. This hampers a systematic assessment of the carbon footprint of a portfolio of financial assets, which is necessary for financial markets to correctly price brown and green assets. Substantial progress needs to be made in implementing, diffusing and enforcing reporting standards. At present, this process is painfully slow. Ideally, both financial and non-financial firms should report both ex-post and ex-ante in terms of projected future emissions.

It is recommended that the SARB address how it can play a crucial role in accelerating the adoption of such a standard reporting system and designing mechanisms to ensure reporting compliance by financial and non-financial firms.

3.2.2 Risk assessment: forward-looking scenarios and financial fragility

Information about the possible evolution of the international distribution of carbon prices across sectors and countries, together with the carbon footprint of South African companies and households, should feed into a risk management system that assesses the systemic risk the South African economy is exposed to and identifies its key sources.

In a stationary environment, the quantification of risk is based on estimates of probability distributions of uncertain relevant events based on past experience. However, the joint process of structural change and evolution of the system of international policies makes traditional risk management approaches ineffective, as these are based on the historical probability distributions of shocks and estimate their effects in calibrated macroeconomic models that assume that the structures of the economy and financial system do not change. This highlights the need to complement the traditional approach with scenario analyses in order to incorporate assumptions about international carbon-pricing policies (and other green policies), structural transformation, and related macroeconomic transmission channels when assessing the response of the macroeconomy and its effects on financial stability.

It is recommended that the SARB devote resources to developing this kind of new approach, building on its expertise in constructing forward-looking scenarios as part of its financial system stress tests. Some central banks have already started developing such scenario analyses. These analyses differ from traditional stress tests as they apply to medium- to long-term horizons about carbon emissions and related carbon-pricing policies to assess macroeconomic-level effects, allowing for sectoral heterogeneity.

3.2.3 Prudential regulation: risk-weighting of assets and capital requirements

In addition to sound monitoring of banks' exposure to risks arising from international mitigation policies (and directly from climate change), the SARB's financial stability (macroprudential) mandate is underpinned by microprudential regulations. Risk-weighted tier one capital requirements are central to those regulations, in line with Basel III rules. At present, South Africa does not apply risk weights that reflect climate risks or risks emanating from international emissions policies; for example, the assets of a bank that is heavily exposed to carbon-intensive industries are not given higher risk weights, which would require the bank to hold greater quantity of costly capital. Developing such a system of risk weights requires an effective system of carbon footprint reporting.

4. Monetary policy

Monetary policy as implemented by the SARB and fiscal policy as implemented by National Treasury play a central role in steering the country's economy. The South African Constitution mandates the SARB to operate monetary policy independently "to protect the value of the currency in the interest of balanced and sustainable economic growth in the Republic". Since 2000, the SARB's policy has been based on an inflation-targeting framework with a government-determined target range for annual inflation of 3–6% (currently interpreted as a mid-range target of 4.5%).

In support of its mandate, SARB is also responsible for maintaining the stability of the financial system. The implications of global climate policies for financial system stability have been discussed in section 3. In this section, we consider their implications for monetary policy, as conducted under the SARB's current mandate.

The SARB's usual conduct of inflation-targeting monetary policy adjusts the policy interest rate to influence future inflation towards its target. It is informed by a forecasting framework in which the economy tends towards its long-run equilibrium, and current or forecast divergence of macroeconomic variables is measured as gaps between them and their long-run equilibrium values. Policy addresses the gaps created by economic shocks that cause disequilibrium, which are normally understood as the shocks that generate business cycles around equilibrium. Monetary policy decisions that target inflation are informed by measurements of:

- **the inflation gap**: the deviation of the rate of inflation from the inflation target;
- **the output gap**: the deviation of the level of output from its potential level;
- **the real interest rate gap**: the deviation of the real (short-term) interest rate from its neutral level; and
- **the exchange rate gap**: the deviation of the real exchange rate from its equilibrium level.[7]

The measure of each gap, out of equilibrium, is treated as the current (or forecast) outcome of shocks. To what extent can the shocks associated with climate change and global emissions policies be addressed within the monetary policy framework?

[7] See Botha et al. (2017) for further detail.

As the world experiences the climate crisis and adopts mitigation policies, various types of shock will affect small, open developing economies such as South Africa's. Since each shock has different implications for monetary policy, it is important to be able to distinguish between them. The following categories provide a framework within which the monetary policy responses of the SARB can be considered.

4.1 Price shocks and the inflation gap

At the centre of global mitigation strategies are moves to raise the price of carbon. These include the adoption of carbon taxes (which include ending fossil fuel subsidies) and the extension of cap-and-trade emissions schemes, with design improvements to overcome the weaknesses of existing schemes. Potentially, the strategy would be supported by an international agreement on a global floor for the carbon price. Measures to increase the price of carbon by South Africa's trading partners for exports will exert upward pressure on South Africa to do the same, and carbon-pricing measures by countries from which South Africa imports (or carbon border taxes by South Africa) will have the same effect.

Overall, such policy moves will have direct effects, raising South Africa's price level, which will register as short-term increases in the inflation gap. The implications for monetary policy will be zero if no indirect effects on the price of labour and of goods and services are foreseeable; policymakers will be able to 'look through' the shock to the same extent as they currently do for supply shocks.

Moreover, to the extent that such price level rises are due to foreseen policy changes in a global mitigation strategy, they are not unforeseen shocks disrupting the policymakers' forecasting framework. It is likely, however, that the global implementation of mitigation policies will also introduce short-term price shocks for countries' implementation of measures, and that their reactions to such measures will be uneven. For example, the global price of fossil fuels might become more volatile as producer cartels fail to achieve a consistent price path, are affected by geopolitical conflict, or meet supply bottlenecks as consumers switch from one type of fossil fuel (such as coal) to cleaner 'transition' fossil fuels (such as liquid natural gas). In the case of a series of such shocks, the SARB's monetary policy framework will need to be able to analyse and respond in a way that keeps inflation expectations stable.

4.2 Structural shocks and the output gap

The structural effects of climate change itself – such as a trend decline in water resources affecting agriculture, electricity generation and manufacturing – affect trend productivity growth and, hence, the growth rate of potential output. If such effects cause a structural negative shift in the growth of potential output, a measure of potential output based on historical data (such as an Hodrick-Prescott Filter estimate) would overestimate the true output gap between potential and actual output and bias monetary policy.

Similarly, other countries' adoption of mitigation policies is likely to have structural effects on South Africa's potential output growth, although the direction of these effects cannot be determined without detailed investigation. Creating tariff and non-tariff barriers to South Africa's major export markets to protect them from a carbon-intensity differential, for example, might disrupt the trade patterns on which current growth strategies are based to such an extent that a structural negative shift in potential output growth may occur. Alternatively, such a policy shock could induce changes in the South African economy towards greener production with higher productivity growth potential. Estimates of the direction of such structural effects of policy shifts will be required to avoid systematic bias in measures of potential output and, hence, the output gap.

4.3 Structural shocks and the real interest gap

Global mitigation measures are intended to change production technologies across economic sectors. The real interest gap, which is the difference between a current rate and a measure of the 'neutral' rate, will be affected to the extent that the latter is changed by such technology shifts. The neutral rate is calculated using several indirect methods relating it to underlying 'real' variables (such as in Laubach and Williams 2003 and Holston, Laubach and Williams 2017). If this rate increases or decreases due to a structural technology shift, monetary policy will be subject to bias unless the SARB is able to quickly and accurately adjust its estimate of the neutral rate. The issue is similar to the effects of mitigation policies on potential output.

4.4 Capital transfer and the exchange rate gap

At the heart of global strategies to mitigate and adjust to climate change are policies that promote the flow of official and private capital towards developing countries. A long-standing objective of the COP process is to effect official transfers of US$100 billion per year (now a target to be reached in 2023); and financial sector initiatives hold the prospect of large private capital flows. A prominent example of an official initiative is an agreement between the governments of South Africa, the US, the EU, France, Germany and the UK, for transfers totalling US$8.5 billion over five years to support South Africa's just transition from coal-dependent electricity generation.

Large capital inflows into a developing country may generate nominal and real exchange rate shocks. The SARB's monetary policy decisions will require careful evaluation of the resulting exchange rate gap measured in its monetary policy framework. At the same time, although the monetary policy framework does not include a nominal exchange rate target, the SARB's implementation of monetary policy in the markets does not take into account foreign exchange market conditions, such as volatility induced by transition-supporting capital flows.

4.5 Operational rules

The recommendation discussed in the preceding paragraphs is that the existing monetary policy framework, which operates through interest rate adjustments and related channels for influencing interest rate and inflation expectations, takes into account the nature of shocks emanating from international mitigation policies and other climate change events.

The usual operation of interest rate policy involves transactions in financial assets (for example, to affect market liquidity), and those operations open possible avenues for the SARB to influence the carbon-intensity of portfolios. The Network for Greening the Financial System (NGFS) lists a number of measures to be considered for incorporation into central banks' operational frameworks for asset transactions, as shown in Table 1. Each potential measure has difficulties associated with it, and their essentially discriminatory character conflicts with the general principle of central banks that market transactions in monetary policy operations should be neutral with regard to the allocation of economic resources.

Table 1: Measures suggested by the NGFS

Credit operations[a]		
(1)	Adjust pricing to reflect counterparties' climate-related lending	Make the interest rate for central bank lending facilities conditional on the extent to which a counterparty's lending (relative to a relevant benchmark) is contributing to climate change mitigation and/or the extent to which they are decarbonising their business model.
(2)	Adjust pricing to reflect the composition of pledged collateral	Charge a lower (or higher) interest rate to counterparties that pledge a higher proportion of low-carbon (or carbon-intensive) assets as collateral or set up a credit facility (potentially at concessional rates) accessible only against low-carbon assets.
(3)	Adjust counterparties' eligibility	Make access to (some) lending facilities conditional on a counterparty's disclosure of climate-related information or on its carbon-intensive/low-carbon/green investments.
Collateral[b]		
(4)	Adjust haircuts[c]	Adjust haircuts to better account for climate-related risks. Haircuts could also be calibrated such that they go beyond what might be required from a purely risk mitigation perspective in order to incentivise the market for sustainable assets.
(5)	Negative screening	Exclude otherwise eligible collateral assets, based on their issuer-level climate-related risk profile for debt securities or on the analysis of the carbon performance of underlying assets for pledged pools of loans or securitised products. This could be done in different ways, including adjusting eligibility requirements, tightening risk tolerance, introducing tighter or specific mobilisation rules, etc.
(6)	Positive screening	Accept sustainable collateral so as to incentivise banks to lend or capital markets to fund projects and assets that support environmentally-friendly activities (e.g. green bonds or sustainability linked assets). This could be done in different ways, including adjusting eligibility requirements, increasing risk tolerance on a limited scale, relaxing some mobilisation rules, etc.
(7)	Align collateral pools with a climate-related objective	Require counterparties to pledge collateral such that it complies with a climate-related metric at an aggregate pool level.
Asset purchases[d]		
(8)	Tilt purchases	Skew asset purchases according to climate-related risks and/or criteria applied at the issuer or asset level.
(9)	Negative screening	Exclude some assets or issuers from purchases if they fail to meet climate-related criteria.

Source: NGFS 2021, Table 1

5. A framework for SARB estimation of financial stability effects (indirect channel)

The ultimate effect of international carbon pricing policies, irrespective of whether they take the form of ETS or taxes, is to charge emitters for the CO2 emissions they are responsible for. In the case of companies, such charging is bound to increase production costs, which will affect these companies' competitiveness.

Companies could be affected in their domestic market if their country operates a carbon-pricing policy and in foreign markets when making export sales to countries where there is a carbon-pricing policy in place. As with any tax, the increase in companies' production costs is partially passed on to other companies in the case of intermediate goods and services and to consumers in the case of final goods and services. The shift to other firms and consumers depends on the elasticity of their demand. Accordingly, abstracting from the domestic channel, the exposure of South Africa's economy to international carbon-pricing policies is primarily related to the international trade of final and intermediate goods and services produced by South Africa and foreign companies. Their cost of production will be affected by international carbon-pricing policies. The intensity of the effects will depend on a company's carbon footprint, which varies across sectors and countries.

We consider intermediate and final goods separately. In the case of final goods, there are two main effects. The first concerns South African consumers of imported goods, while the second concerns South African firms that export their goods and services to other countries. The price of imported final goods will increase because foreign firms that are subject to carbon-pricing policies in their country of origin or in other countries in which they operate will increase the price at which they sell to South African customers.

Such price effects will be determined according to the pricing strategy of these firms and will generally depend on how green these firms are, how quickly they are able to adjust to reduce their emissions if needed, and how elastic South African consumers' demand is both in absolute value and relative to consumers in other countries. The financial sustainability of firms might be affected if consumers cannot substitute imported goods with other greener goods and services. If South African consumers substitute greener products for imports whose price has increased due to carbon pricing, firms that provide import-related services will be adversely affected. They will see a negative effect on their expected future profitability and, ultimately, on the viability of their current business in the medium to long term if no structural change is made to their business strategy. Finally, South Africa's final goods producers will be directly affected if they export their products to countries that have a carbon-pricing policy. These firms will face an increase in the cost of production; those that are less green to begin with will be affected to a greater extent, which will make them less competitive in foreign markets.

There are two main channels through which intermediate goods will be affected by carbon-pricing policies. Firstly, South African companies that export intermediate goods to countries where carbon-pricing policies are in place will be directly affected. Secondly, those firms whose domestic or foreign suppliers face an increase in their production costs due to carbon policies would also be affected. Notably, there is another potentially relevant indirect effect: South African companies might face a cost increase if they are using raw materials and intermediate goods produced in countries that are not implementing measures to mitigate carbon emissions. This is because such inputs might increase the carbon footprint of South African products, resulting in a higher cost of production of South African final and intermediate goods exported to markets where carbon-pricing policies are active.

The strength of these price and cost shocks that would affect South African households and firms would vary across sectors. In sectors characterised by relatively low emissions, foreign firms will be less affected by international carbon policies, resulting in smaller price increases faced by South African consumers and firms buying final and intermediate goods, respectively. Similarly, South African exporting firms in low-emission sectors will be less affected than their counterparts in high-emission sectors.

With this in mind, a framework the SARB could use to monitor financial stability effects and provide a qualitative assessment of the potential exposure of South Africa's banking sector (or broader financial sector) to risks related to international mitigation policies comprises the following elements:

1. identifying key trading partners and quantifying the relative size of international trade flows compared to the size of the economy, which will provide information about the impact that international markets have on the operations of South African firms;
2. providing a breakdown of trade flows into industrial sectors, given that the intensity of emissions varies across sectors, and calculating the intensity of emissions across trading partners;
3. in scenario analyses, using information about key partners and the sector composition of trade flows to estimate the trade and sector effects of international carbon-pricing policies under different assumptions about the evolution of these effects; and
4. calculating the effect of shocks to emissions-dense sectors on the assets held in financial firms' portfolios.

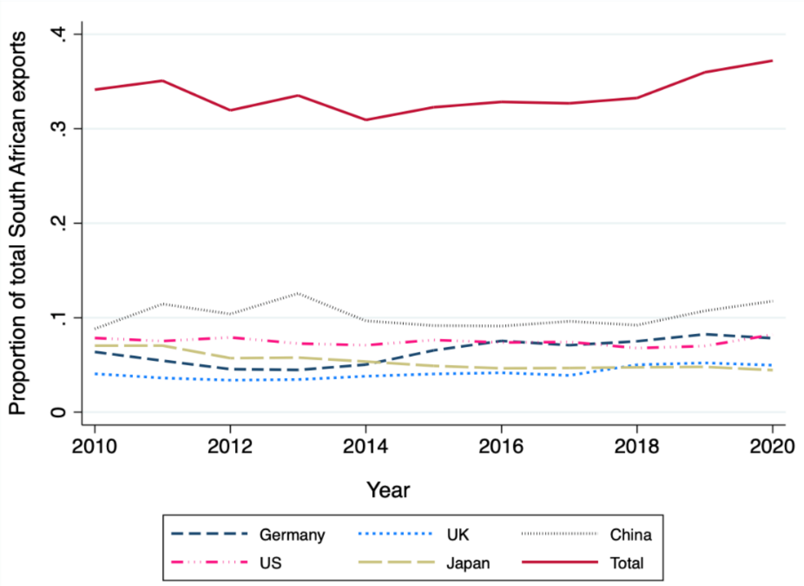
In the following section, we apply this framework to illustrate its potential value and highlight the data limitations that need to be addressed.

5.1 South African foreign trade: leading partners and main sectors

To examine the effects of foreign countries' emission-reducing measures on the South African economy and how those real economy effects impact the financial sector, we need to identify the economic sectors that are most affected by trading with foreign partners. We identify first the major trading partners, before turning to the sectoral decomposition of trading flows.

The top five countries to which South African firms export their goods are China, the US, Japan, Germany and the UK. In 2020, on average, on a monthly basis, South Africa exported 11.75% of its goods to China, 7.9% to the US, 7.82% to Germany, 4.97% to the UK and 4.45% to Japan. The trends over the decade from 2010 to 2020 are shown in Figure 6.

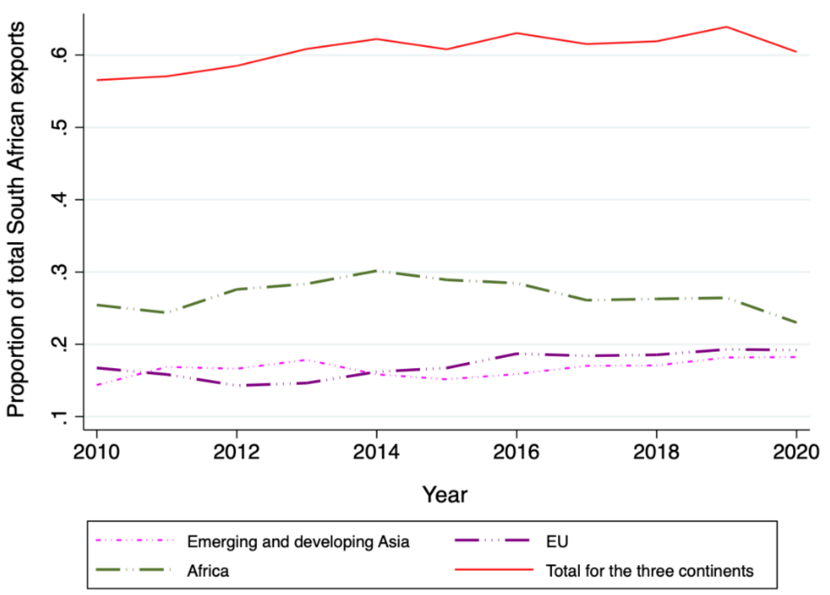
Figure 6: Top importers of South African goods



Source: IMF and the authors

Germany, the UK, China, the US and Japan account for more than 35% of South African exports. On a continental level, the main foreign markets for South African exports are Africa (23% of total exports) – in particular, sub-Saharan Africa (22.8%) – the EU (19.2%), and Asian emerging and developing countries (18.23%). Trends are shown in Figure 7.

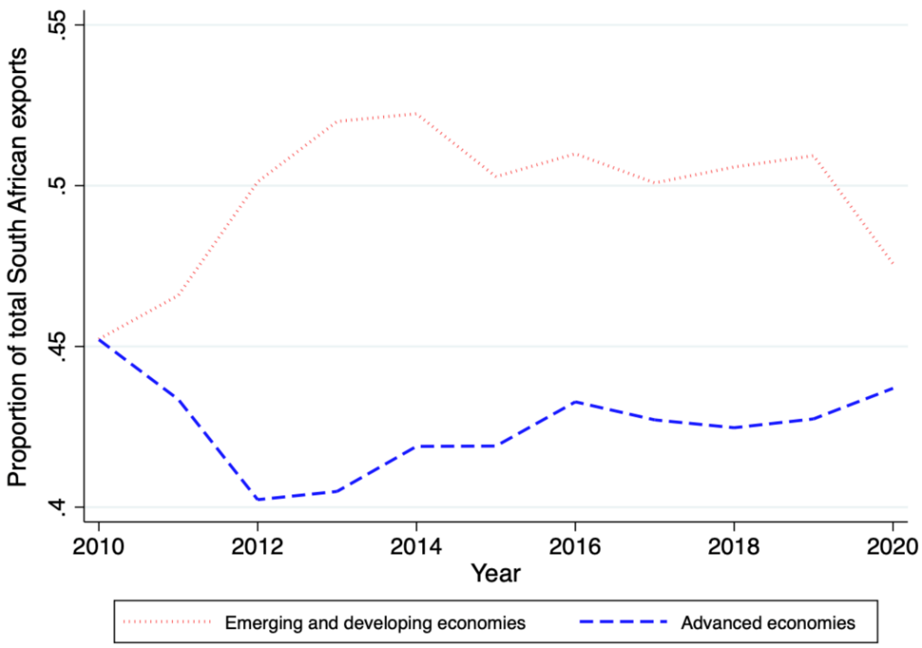
Figure 7: Main importers of South African goods on a continental level



Source: IMF and the authors

About 48% of South Africa's exports go to emerging or developing countries, while 42% of exports go to advanced economies. Figure 8 illustrates these trends.

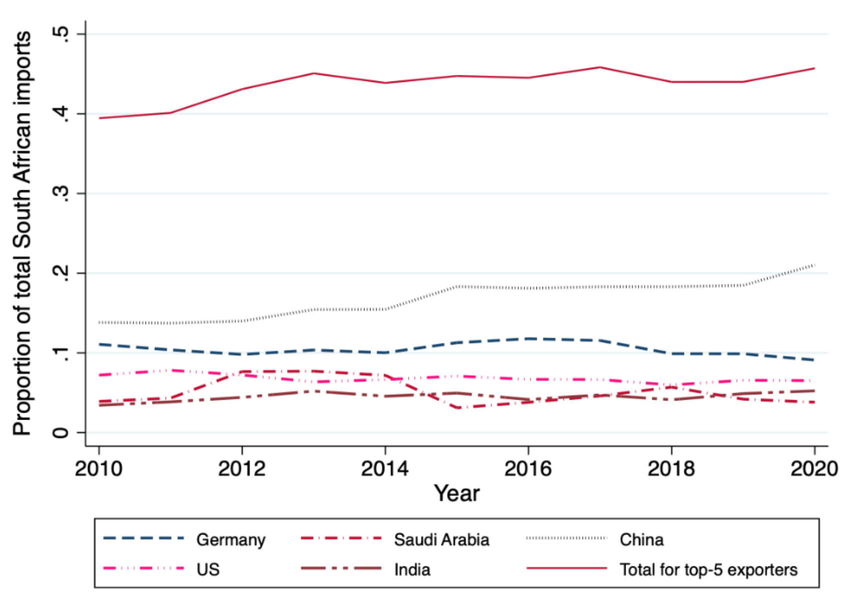
Figure 8: Importance of developing and developed countries



Source: IMF and the authors

The top five foreign suppliers of raw materials and intermediate and final goods to South Africa are China, Germany, the US, India and Saudi Arabia. In 2020, on a monthly basis, South Africa imported an average of 21.04% of its total imports from China, 9.10% from Germany, 6.51% from the US, 5.24% from India and 3.81% from Saudi Arabia. Figure 9 shows the relative trends for the 10 years from 2010 to 2020.

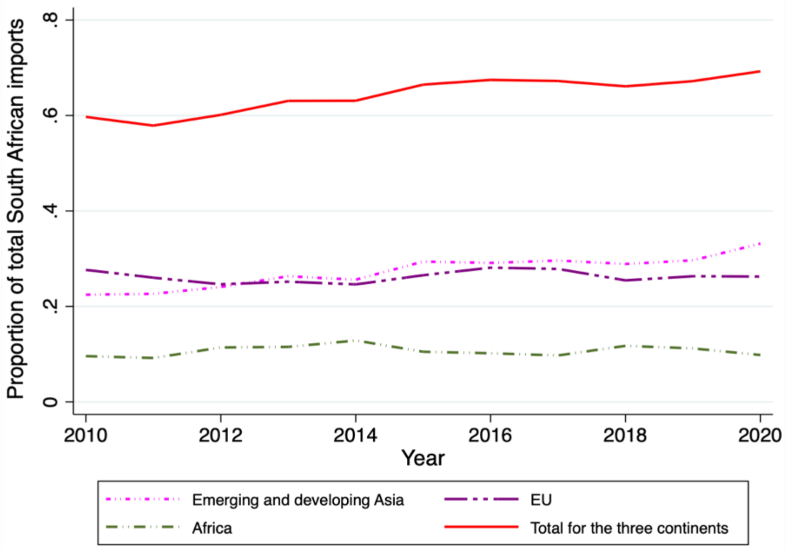
Figure 9: The top five exporters to South Africa



Source: IMF and the authors

At a continental level, South Africa's main suppliers were Asian emerging and developing countries (33.15% of total imports), the EU (26.26%) and Africa (9.83%, of which 9.66% was from sub-Saharan Africa). These trends are reflected in Figure 10.

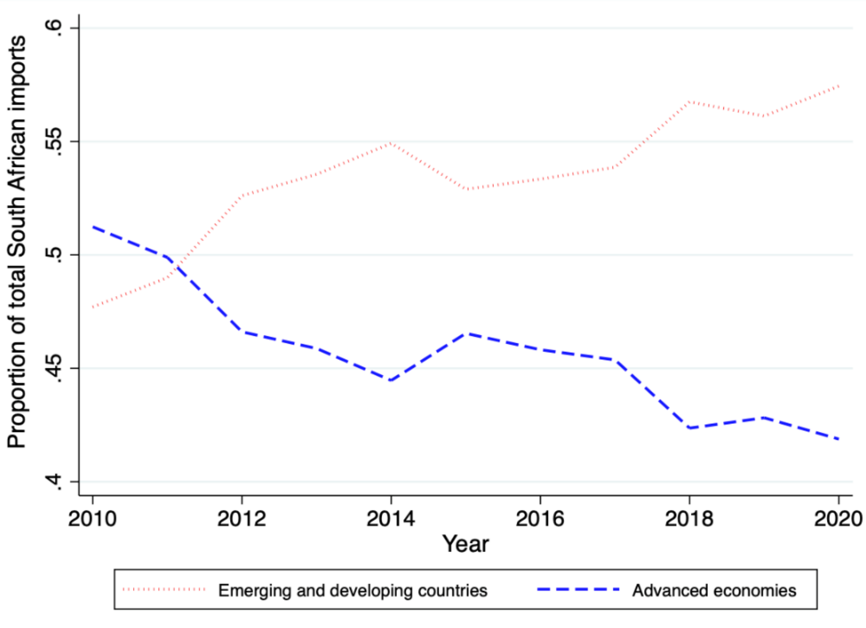
Figure 10: Main suppliers of South Africa on a continental level



Source: IMF and the authors

About 58% of South Africa's imports comes from emerging and developing economies, while 42% come from advanced ones. These trends are shown in Figure 11.

Figure 11: The importance of developing and developed countries as suppliers to South Africa



Source: IMF and the authors

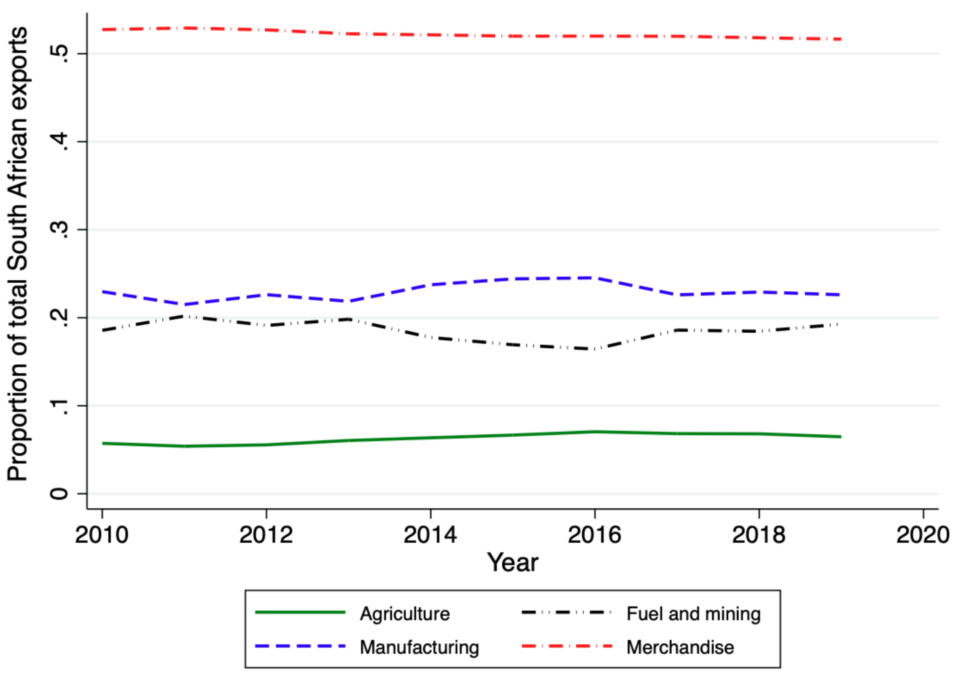
5.2 Composition of trade flows: final and intermediate goods

To the extent that carbon content varies across different production sectors, the sectoral composition of trade with the main partners is also relevant in order to evaluate South Africa's exposure to carbon policy-related risks. According to World Trade Organization (WTO) data, at the aggregate level, in 2019, the composition of South African trade (Standard International Trade Classification Revision 3 (SICT3) level of aggregation) was as follows:

- **Imports:** merchandise: 57.28%; agriculture: 3.83%; fuel and mining: 9.12%; manufacturing: 29.75%.
- **Exports:** merchandise: 51.64%; agriculture 6.47%; fuel and mining 19.27%; manufacturing: 22.6%.

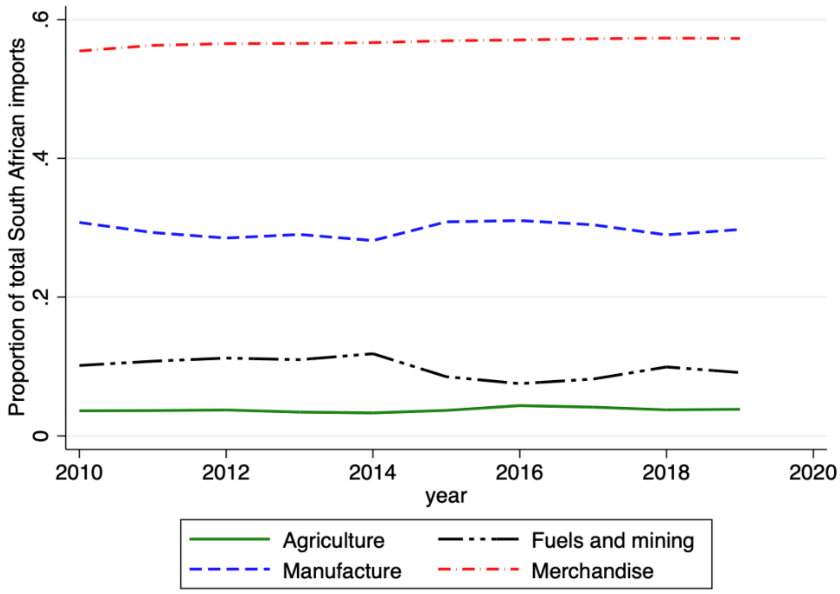
Figures 12 and 13 show the 10-year trend.

Figure 12: Composition of exports (Level SICT3)



Source: WTO and the authors

Figure 13: Composition of imports (Level SICT3)



Source: WTO and the authors

Tables 2 and 3 show the sectoral composition of South Africa's trade with its main trading partners. The tables reflect the percentage composition at SICT2 level of product aggregation for exports and imports, respectively, for the year 2019, based on World Integrated Trade Solution statistics.

Table 2: Sector composition of South African exports to its main markets

Country	Textiles	Food	Manu-facturing	Chemicals	Fuel	Ores & metals	Agricultural materials	Machinery & transport
China	2.03	3.96	13.86	1.93	0.17	78.02	3.97	0.93
Japan	0.07	2.66	20.12	1.73	0.80	71.78	4.66	10.55
US	0.58	6.48	41.12	9.99	1.59	49.96	0.67	16.51
UK	0.70	15.52	33.17	1.63	0.23	49.788	1.18	27.81
EU & Central Asia	1.07	12.02	58.2	6.53	1.35	26.55	1.56	41.36
Sub-Saharan Africa	3.08	16.50	63.32	12.62	13.04	6.00	0.90	25.54

Source: WTO and the authors

Table 3: Sector composition of South African imports from its main markets

Country	Textiles	Food	Manu-facturing	Chemicals	Fuel	Ores & metals	Agricultural materials	Machinery & transport
China	9.90	1.35	93.42	8.25	0.89	1.72	0.64	51.48
India	4.66	5.06	71.93	20.65	19.77	0.76	0.29	36.2
US	0.93	5.40	79.15	18.05	5.93	0.58	1.80	43.98
Saudi Arabia	0.14	0.11	11.47	10.77	87.16	1.24	0.00	0.07
EU & Central Asia	1.09	8.21	71.34	16.36	3.04	1.98	0.40	34.57
Sub-Saharan Africa	7.48	10.94	24.30	6.20	56.31	3.36	1.76	4.94

Source: WTO and the authors

5.3 Geography and sectoral composition of emissions

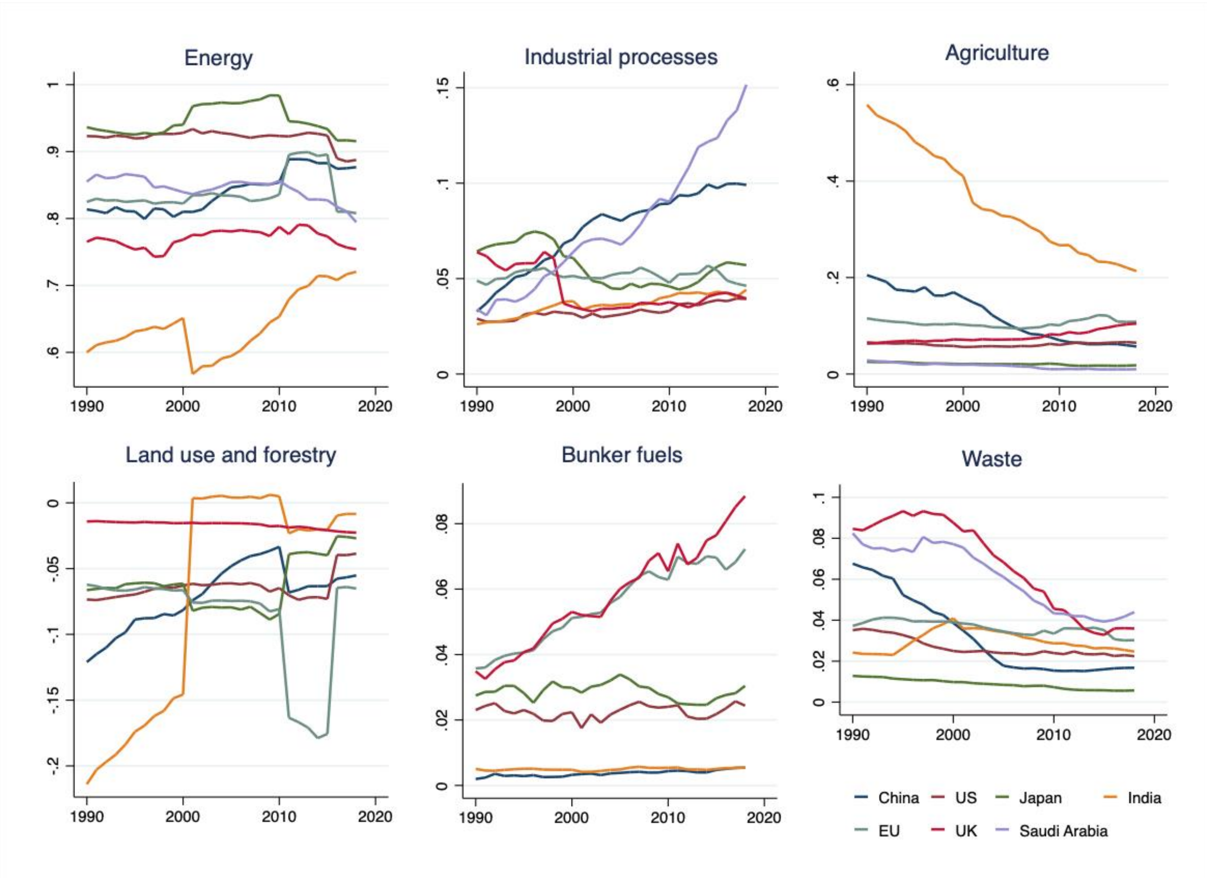
The CO2 emissions of a country, or a group of countries, can be disaggregated by considering the sectors from which the emission originates. Our World in Data (ourworldindata.org) provides data disaggregated into the following sectors: energy (electricity, heat and transport); direct industrial processes; waste; agriculture, forestry and other land use. As Figures 14 and 15 show, the distribution of emissions over these sectors is qualitatively the same across South Africa's leading trading partners: China, the UK, the US, the EU, India, Japan, Saudi Arabia (Figure 14) and South Africa itself (Figure 15). By far, energy production for use by various sectors, such as manufacturing, agriculture, and mining and fuel (and the production of goods and services that characterise South African exports and imports, as discussed in section 4), is consistently responsible for the most emissions across countries. Energy, direct industrial processes and agriculture also contribute significantly to CO2 emissions. If we consider 2018:

1. energy accounted for 87.7% of emissions in China; 91.6% in Japan; 71.68% in India; 75.4% in the UK; 88.6% in the US; 80.8% in the EU; 79.5% in Saudi Arabia; and 83.99% in South Africa;

2. industrial processes accounted for 9.98% of emissions in China; 5.78% in Japan; 4.06% in India; 4.12% in the UK; 3.96% in the US; 4.74% in the EU; 13.82% in Saudi Arabia; and 4.06% in South Africa; and

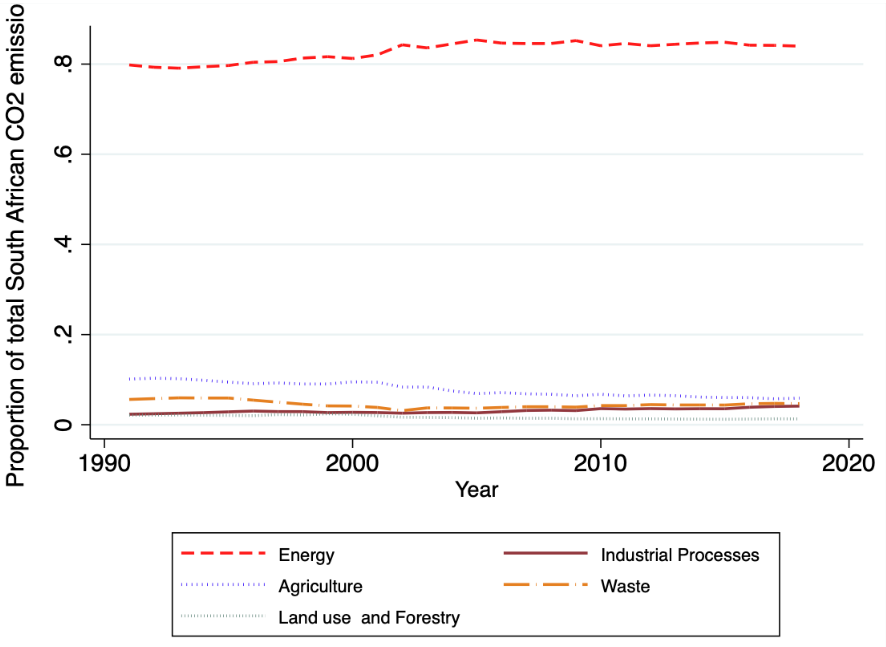
3. agriculture accounted for 5.97% of emissions in China; 1.74% in Japan; 22.04% in India; 10.31% in the UK; 6.63% in the US; 10.80% in the EU; 0.95% in Saudi Arabia; and 5.74% in South Africa.

Figure 14: Sectoral distribution of CO2 emissions



Source: Our World in Data and the authors

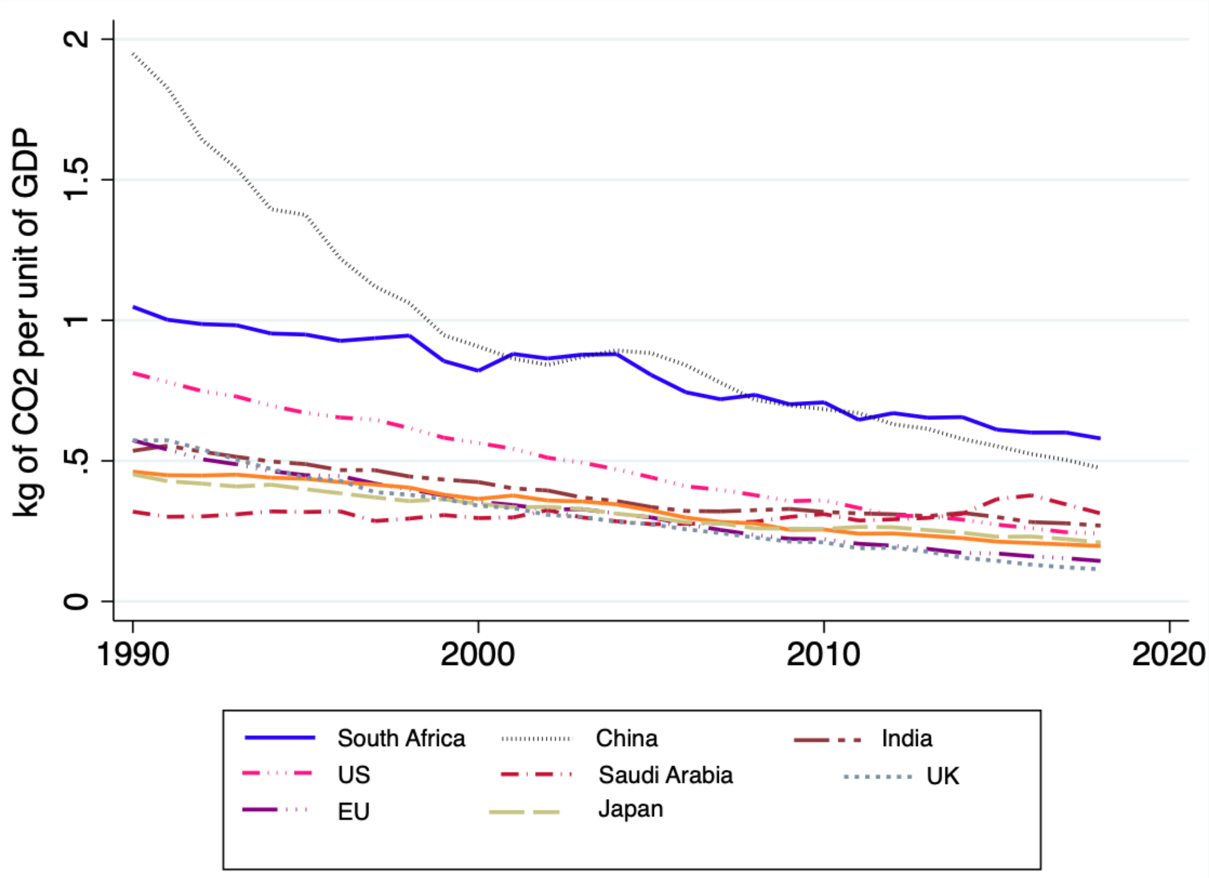
Figure 15: Sectoral distribution of CO2 emissions for South Africa



Source: Our World in Data and the authors

How clean is the energy used in South Africa's direct industrial processes and agriculture compared to its trading partners? Figure 16 shows the CO2 emissions per unit of GDP across countries. South Africa has the highest level of emissions per unit of GDP together with China. Other trading partners are greener than South Africa. For instance, in 2018, kilogrammes of CO2 per unit of GDP in purchasing power parity were as follows: South Africa: 0.58; China: 0.48; Saudi Arabia: 0.32; India: 0.27; the US: 0.25; Japan: 0.21; sub-Saharan Africa: 0.20; the EU and Central Asia: 0.19; and the EU: 0.15.

Figure 16: CO2 emissions per unit of GDP in trading partner countries and in South Africa



Source: Our World in Data and the authors

If we combine these data with those on the relative weight of emissions stemming from the energy sector, we find that the CO2 produced by the energy sector per unit of GDP varies across countries, as shown in Table 4.

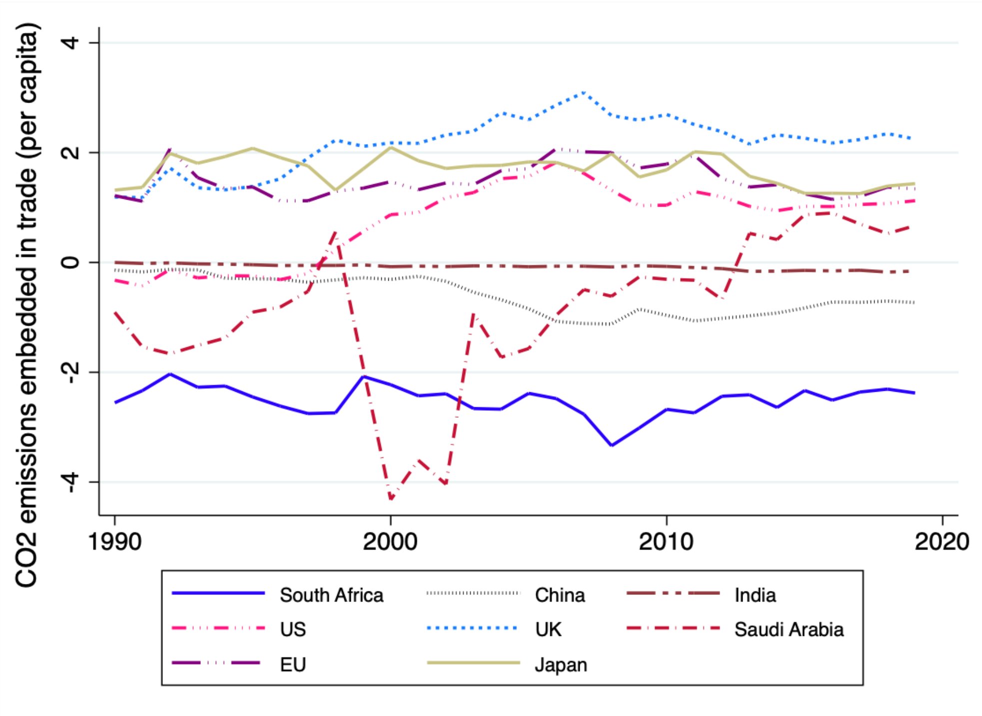
Table 4: Energy-related emissions per unit of GDP

Country	Kg of CO2 per unit of GDP
South Africa	83.99% x 0.58 = 0.49
China	9.98% x 0.48 = 0.047
Saudi Arabia	79.5% x 0.32 = 0.26
US	88.6% x 0.25 = 0.22
Japan	91.6% x 0.21 = 0.20
India	71.68% x 0.27 = 0.20
EU	80.8% x 0.15 = 0.13
UK	88.6% x 0.12 = 0.11

Source: Our World in Data and the authors

Table 4 shows that in 2018 South Africa's energy sector was less clean than that of any its trading partners, and much less clean than that of key partners such as the EU and the UK. The above evidence suggests that South Africa is significantly less green than most of its trading partners. This is confirmed by the comparison between production-based emissions and consumption-based emissions shown in Figure 17, which indicates that South Africa is a net exporter of CO2.

Figure 17: Net exporters (negative values) and net importers of CO2



Source: Our World in Data and the authors

5.4 The emissions intensity of banks' asset portfolios

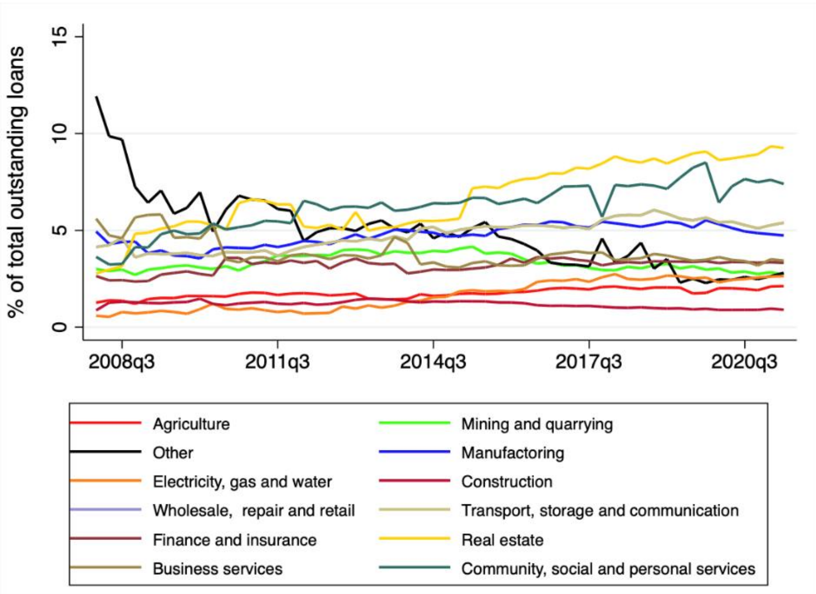
To complete the analysis of the effect of international emissions policies on financial stability through the indirect channel, data on the emissions content of banks' asset portfolios are required but, as previously noted, are not currently held by the Prudential Authority within the SARB. In its absence, we use data provided by the Prudential Authority showing the sectoral distribution of banks' assets.

Figure 18 shows the evolution of the portfolio composition of outstanding loans of the South African banking sector[8] (excluding the household sector, which accounts for more than 40% consistently throughout the sample period). It shows that the sectoral

[8] The data is for the five largest banks, which account for 90 per cent of bank assets.

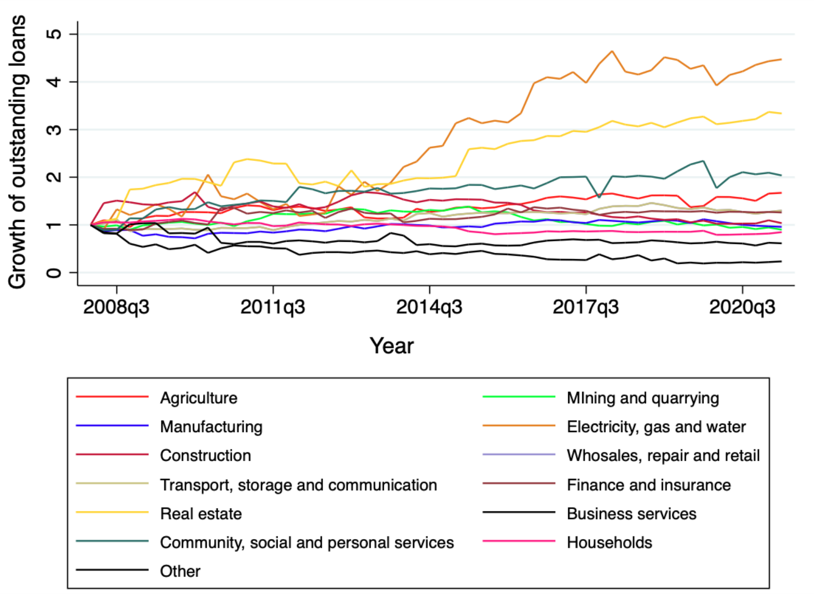
composition of bank credit portfolios became more polarised, increasing its concentration in the electricity, gas and water sector; the real estate sector; and the community, social and personal services sector. Whereas in 2008 there is no one sector that accounts for more than about 5% of total loans, by 2020 the electricity, gas and water sector and the real estate account for almost 10%. As shown in Figure 19, such polarisation is the result of the sharp growth of loans in these two sectors. Increased sectoral concentration itself increases fragility relative to more diversified portfolios; in relation to the effect of international mitigation policies, it is significant that banking portfolios have become increasingly concentrated in two emissions-intensive sectors.

Figure 18: Evolution of credit exposure of the South African banking system by sector



Source: SARB and the authors

Figure 19: Growth of credit exposure of the South African banking system by sector



Source: SARB and the authors

5.5 The South African economy's exposure to international carbon-pricing policy risks

To determine the geographical and sector composition of risks South Africa faces related to international carbon policies, we have found it helpful to combine information on:

- South Africa's leading foreign trade partners;
- South Africa's significant import/export sectors;
- the C02 contribution of main sectors per unit of GDP in purchasing power parity in South Africa and its trading partners;
- carbon-pricing policy trends in trading partner countries; and
- the role of the energy sector.

As far as the geography of potential risk is concerned, the analysis conducted in section 4.1 reveals that South Africa's main export markets (representing the destinations of more than 80% of the country's total exports) are:

- **Single countries:** China, Japan, the US and the UK;
- **Regions:** the EU, sub-Saharan Africa, and emerging and developing Asia.

Similarly, the main markets from which imports originate (more than 80% of total imports), that is, South Africa's main foreign suppliers, are:

- **Single countries:** China, the US, India and Saudi Arabia;
- **Regions:** the EU, sub-Saharan Africa, and emerging and developing Asia.

Therefore, examining the evolution of carbon-pricing policies in these countries and regions plays a crucial role in determining the risk exposure of the South African economy, as well as how these policies contribute to the systemic financial risks faced by the country.

We turn now to the composition of international trade in terms of goods and services. Based on our analysis in section 4.2, in terms of South Africa's exports, the leading goods and services production sectors (ranked in decreasing order of relevance) are:

- ores and metals
- manufacturing
- machinery and transportation equipment
- food

As for imports, the main product and services sectors (ranked in decreasing order of relevance) are:

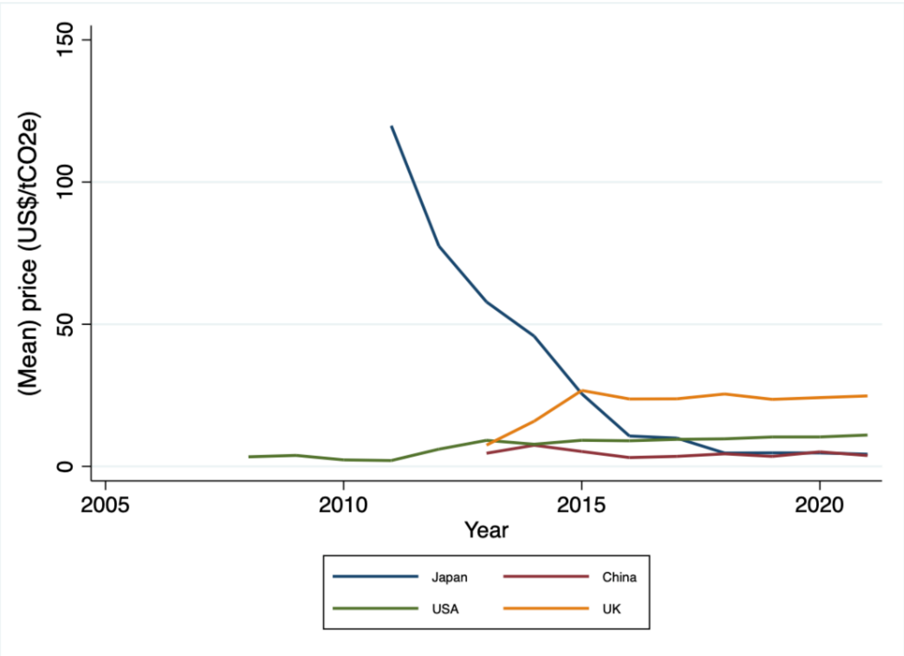
- manufacturing
- fuel
- machinery and transport
- chemicals

For both imports and exports, the potential contribution to systemic risk will depend on the carbon content of these sectors. In other words, the carbon footprint of domestic South African companies and of foreign companies exporting goods and services to South Africa is crucial. Concerning domestic production, given that energy production in South Africa is particularly CO2-intensive, a crucial determinant of the carbon footprint of domestic firms will largely depend on how energy-intensive the production sector in which they operate is. In that respect, we note that, according to Our World in Data, on average, globally, energy use in industry accounts for around 33% of energy-related emissions, transportation for 22.5%, building for 24%, and agriculture and fishing for 2.4%.

In the case of imports, as discussed, it is essential to disaggregate supplies of intermediate goods to be used in the production of goods for the foreign and domestic markets, respectively, as well as the provision of final goods to be consumed by South African households. In each of the three cases, the impact of carbon prices on the financial system's stability operates differently. Moreover, in all cases, the risk exposure will depend on the evolution of carbon prices that firms importing to South Africa and exporting from South Africa face.

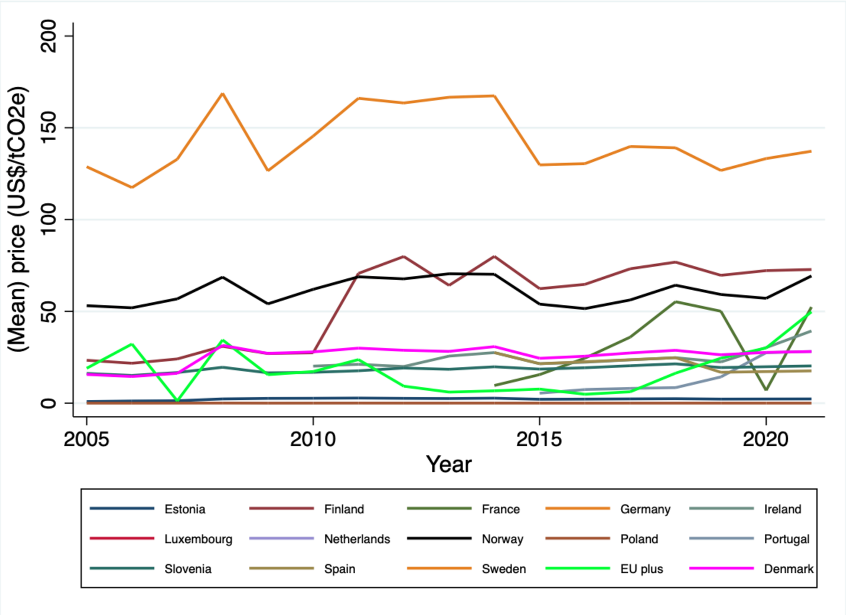
Figures 20 and 21 present the historical trends of carbon prices implied by active ETSs and carbon taxes for countries and regions that are leading trading partners of South Africa, as discussed in section 3.

Figure 20: Price of carbon resulting from carbon taxes/ETSs among South Africa's leading trade partners



Source: World Bank and the authors

Figure 21: Price of carbon resulting from carbon taxes/ETSs in the EU and its member countries



Source: World Bank and the authors

6. Recommendations

The imposition of carbon border taxes by South Africa's major trading partners such as the EU has implications for the SARB in ensuring the country's financial stability and managing its monetary policy. The following recommendations are based on the analysis and discussion in the preceding sections of this paper.

We recommend that the SARB develop a framework for estimating and monitoring the impact of international climate mitigation policies on South Africa's financial stability. The SARB needs to generate, gather and maintain detailed data on South Africa's trading partners' new or extended carbon border taxes and other climate mitigation and adaption measures. This data needs to be disaggregated to individual banks (and non-bank financial firms) and reflect the carbon intensity of firms whose liabilities are held in banks' asset portfolios.

The SARB can play a key role in accelerating the adoption of standard reporting systems relating to firms' carbon-reduction strategies, and designing mechanisms to ensure that financial and non-financial firms comply with reporting requirements.

We recommend that the SARB devote resources to developing scenario analyses (and implementing internationally designed scenario analyses) of how international emission mitigation strategies and other climate-related shocks affect financial stability.

Since microprudential soundness is one pillar of financial stability, the Prudential Authority should consider applying risk weights that reflect climate risks or risks emanating from international emissions policies in its calculation of risk-weighted capital requirements.

The gap analysis that is central to the SARB's decision-making on monetary policy provides a useful framework for taking into account how the carbon border taxes of South Africa's major trading partners could affect monetary policy outcomes. It is for this reason that changes in South Africa's neutral interest rate and potential output that are induced by policies related to climate change need to be robustly estimated.

References

Battiston, S. 2019. ‘The importance of being forward-looking: managing financial stability in the face of climate risk’. *Banque de France Financial Stability Review* 23: 39–48.

Battiston, S, Mandel, A, Monasterolo, I, Schütze, F and Visentin, G. 2017. ‘A climate stress-test of the financial system’. *Nature Climate Change* 7(4): 283–288.

Bolton, P and Kacperczyk, M. 2020a. ‘Do investors care about carbon risk?’ *Journal of Financial Economics*, forthcoming.

Bolton, P and Kacperczyk, M. 2020b. ‘Global pricing of carbon-transition risk’. *Journal of Finance*, forthcoming.

Bolton, P, Kacperczyk, M, Harrison, H and Vives, X. 2021. ‘Resilience of the financial system to natural disasters’. *The Future of Banking Series*, No. 3. London: Centre for Economic Policy Research (CEPR).

Bolton, P, Despres, M, Pereira da Silva, L, Samama, F and Svartzman, R. 2020. ‘The green swan: central banking and financial stability in the age of climate change’. Bank of International Settlements and Banque de France.

Botha, B, de Jagar, S, Ruch, F and Steinbach, R. 2017. ‘The Quarterly Projection Model of the SARB’. *South African Reserve Bank Working Paper Series*, WP/17/01.

Cahen-Fourot, L, Campiglio, E, Dawkins, E, Godin, A and Kemp-Benedict, E. 2019. ‘Capital stranding cascades: the impact of decarbonisation on productive asset utilisation’. *Ecological Economic Papers*, No. 18. University of Vienna.

Carbon Brief. 2018. ‘Q&A: How “integrated assessment models” are used to study climate change’. https://www.carbonbrief.org/qa-how-integrated-assessment-models-are-used-to-study-climate-change/.

Cheng, H and Ishikawa, J. 2021. ‘Carbon tax, cross-border carbon leakage, and border tax adjustments’. Vox EU, CEPR. https://voxeu.org/article/carbon-tax-cross-border-carbon-leakage-and-border-tax-adjustments.

European Central Bank. 2020. 'Guide on climate-related and environmental risks: supervisory expectations relating to risk management and disclosure'. https://www.bankingsupervision.europa.eu/ecb/pub/pdf/ssm.202011finalguideonclimate-relatedandenvironmentalrisks~58213f6564.en.pdf.

Giglio, S, Kelly, B T and Stroebel, J. 2020. 'Climate finance'. National Bureau of Economic Research Working Paper No. 28226.

Giglio, S, Maggiori, M, Stroebel, J and Weber, A. 2021. 'Climate change and long-run discount rates: evidence from real estate'. *Review of Financial Studies*, forthcoming.

Holston, K, Laubach T and Williams, J C. 2017. 'Measuring the natural rate of interest: international trends and determinants'. *Journal of International Economics* 108(S1): 59–75.

Hoogendoorn, S, Trinks, A and Bollen, J. 2021. 'Carbon pricing and relocation: evidence from Dutch industry'. Vox EU, CEPR. https://voxeu.org/article/carbon-pricing-and-relocation-evidence-dutch-industry.

International Energy Agency. 2020. 'South African Carbon Tax'. https://www.iea.org/policies/3041-south-african-carbon-tax.

Laubach, T and Williams, J C. 2003. 'Measuring the natural rate of interest'. *Review of Economics and Statistics* 85(4): 1 063–1 070.

Network for Greening of the Financial System (NGFS). 2019. 'Macroeconomic and financial stability: implications of climate change'. Technical supplement to the first comprehensive report. https://www.ngfs.net/sites/default/files/medias/documents/ngfs-report-technical-supplement_final_v2.pdf (accessed 8 August 2022).

NGFS. 2020. 'NGFS climate scenarios for central banks and supervisors'. Technical document. https://www.ngfs.net/sites/default/files/medias/documents/820184_ngfs_scenarios_final_version_v6.pdf (accessed 8 August 2022).

NGFS. 2021. 'Adapting central bank operations to a hotter world: reviewing some options'. Technical document. https://www.ngfs.net/sites/default/files/media/2021/06/17/ngfs_monetary_policy_operations_final.pdf (accessed 8 August 2022).

Parry, I, Black, S and Roaf, J. 2021. ‘Proposal for an international carbon price floor among large emitters’. International Monetary Fund Staff Climate Notes 2021/001. Washington DC.

Tirole, J. 2019. ‘Institutional and economic challenges for central banking’ in *Monetary policy: the challenges ahead*. ‘A colloquium in honour of Benoît Coeuré, 17–18 December 2019. European Central Bank. 34–40.

Verde, S F. 2020. ‘The impact of the EU emissions trading system on competitiveness and carbon leakage: the econometric evidence’. *Journal of Economic Surveys* 34(2): 320–343.

World Bank. 2021. ‘State and trends of carbon pricing 2021’. Washington DC.