Estimating the carbon emissions balance for South Africa

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Abstract

The carbon footprint of materials and products is becoming an increasingly important factor in international trade. At present the carbon emissions balance of the South African economy is not well understood, especially the carbon emissions associated with imports and exports. An investigation was done of known economic input-output and life cycle analyses models addressing this shortcoming. The results reveal that South Africa is a major exporter of carbon; at least 129 per cent more carbon is associated with a dollar earned with exports than a dollar spent on imports, and the carbon footprint of the outflows on average, equates 37 per cent of the total carbon emissions of the economy. Such figures have serious policy-related implications in a future where international climate-change trade limitations will become stricter and binding.

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1 Introduction

Trade and the environment are the two issues that are at the epicentre of the globalisation debate (Williams, 2001; Nordström & Vaughan, 1999). With growing environmental awareness multilateral trade liberalisation may offer the global population access to less-polluting products and processes. However, there is evidence that liberalised trade and increased incentives for exports from developing countries leads to greater exploitation of natural resources (Mukhopadhyay & Chakraborty, 2005a). For example, the transformation of land to produce and export biofuels has not only destroyed native forests, but has also significantly increased the carbon footprint of some biofuels (Fargione *et al*.., 2008). Furthermore, free trade has been shown to promote and facilitate the translocation of polluting industries to developing countries with less strict environmental regulations (Mukhopadhyay & Chakraborty (2005b)[1].

A specific environmental concern, as part of the global climate change focus, is the carbon footprint[2] of developing-country products that are bought by developed countries (Shui & Harriss, 2006; Kejun et al., 2008). Indeed, the observed decrease in the energy intensity, and therefore the associated CO_2 equivalent

(CO_2e) emissions[3], for developed countries may partly be attributed to an increase in the importation of 'embodied' carbon from developing countries (Suri & Chapman, 1998). To this end, environment-related issues may actually be used as trade barriers in terms of protecting local (foreign) markets (Fontagné et al., 2001). Studies have consequently been undertaken in developed (Mongelli et al., 2006) and developing (Machado et al., 2001) countries to understand the potential carbon embodied in the products that are traded with these countries.

The paper applies a similar approach to the studies of Mongelli et al. (2006) and Machado et al. (2001) with the goal to provide an improved quantification of the carbon emissions balance of South Africa, especially in terms of how the balance relates to imports and exports. It is expected that a better understanding of South Africa's carbon balance will inform Government formulation of environmentally-related regulations and policies – carbon trading and carbon taxes in particular – that not only promote and protect its environment and people, but also the competitiveness of its economy. For example, regulations, standards, taxes, and possibly even subsidies or tax relief, need to be put in place to accelerate the implementation of carbon-credit schemes, within the voluntary and Kyoto flexibility mechanisms, and to foster innovation and adoption of clean technologies in the South African economy (Little et al., 2007). This is essential where stricter carbon-emission limitations are being set and enforced in developed countries and pressures are mounting on developing countries.

2 An input-output (IO) analysis approach to carbon balances

The contribution of international trade to global energy demand and greenhouse-gas emissions has been analysed by input-output (IO) specialists, as listed by Machado et al. (2001). IO analysis is a well-established linear economic model often used to account for economic and environmental consequences or impacts following a change in the total output of an economy (Suh, 2004). IO approaches have played a central role in performing analyses of policy-driven material and product flows. Giljum et al. (2007) note that these approaches open up the "black box" of economy-wide material flow analyses and therefore provide information on tariff groups and product-specific resource flows and resource productivity. By applying these approaches, environmentally important sectors and products ("hot spots") can be identified and ranked. Giljum et al. (2007) provide a history of the development of these techniques, and Mongelli et al. (2006) describe the underlying mathematical principles.

A major advantage of the IO approach, compared to the conventional, standardised environmental Life Cycle Analysis (LCA) approach that focuses on a specific material or product (Brent, 2003), is that it avoids imprecise definitions of system boundaries; the entire national economic system is the scope for the analysis. It also allows for the estimation of the total resource inputs for all types of products with less effort than the LCA-based method (Giljum et al., 2007). Furthermore, it allows analyses at different spatial scales (Munksgaard et al., 2005). The major disadvantage of the IO approach, however, is the high level of aggregation of economic sectors, which impede the analysis of specific materials and products and lead to problems of heterogeneities within economic sectors. Notwithstanding this, the IO approach is argued to be a relatively robust way of obtaining estimates of the carbon footprint of materials and products, for the purpose of international trade investigation in both developed and developing countries (Mongelli et al. 2006; Machado et al., 2001). To this end Tukker et al. (2009) call for the standardisation of the environmental IO approach to allow analyses at global and multi-regional levels.

At present no IO model has been developed for the South African economy that can determine the total carbon emissions associated with exported products. And, on the import side, since South Africa trades with many different countries no single available IO database can accurately reflect the carbon emissions associated with imported products. The lack of appropriate IO models for both exports and imports makes it necessary to modify and use models developed by others for other economies. The following countries were found to have recently conducted environmental IO studies at sectoral and/or country-wide level:

- Australia (Foran et al., 2004).
- Denmark (Weidema et al., 2005).
- Portugal (Ferrao and Nhambiu, 2006).
- Brazil (Lenzen & Schaeffer, 2004).
- United States and Canada (Hendrickson et al., 2006)

In this study, we use the EIO-LCA model of the Green Design Institute at Carnegie Mellon (2008) because it is readily available, transparent, is an example of a tried-and-tested combination of IO and LCA approaches, and has been applied to various countries (Cicas et al., 2007). The details of the model are described by Hendrickson *et al*. (2006). A consequence of there not being an IO model for South Africa, and all the countries it imports from, is the uncertainties associated with applying other models. Where possible the uncertainties were reduced by utilising available LCA data for South Africa; otherwise the implications of the uncertainties were considered in the investigation summarised in this paper.

3 Research method and results

Four steps were undertaken to estimate the carbon balance of South Africa.

Step 1: Rank all imported and exported products

A comprehensive database of South African imports and exports was obtained from the South African Revenue Service (SARS, 2008) and the list of flows was verified against the original input-output tables of StatsSA (1993); the flows are updated from time to time. The data provide details of the flows of these products for the 2007 fiscal year in terms of their tariff groups and descriptions, physical quantities, and economic values (South African Rand (ZAR)). The import and export flows were then ranked based on their economic values to establish the products that substantially influence the South African international trade balance. The top twenty import and export products are listed in Tables A1 and A2 in the Annexure, respectively. These top 20 products make up about 62 per cent of the total imports and 79 per cent of the total export values. The remainder of South Africa's trade balance is made up of many, but relatively low-valued products, mainly because the quantities imported and exported[4] are relative small.

Step 2: Assign carbon emissions from the EIO-LCA database

The EIO-LCA model of the Green Design Institute at Carnegie Mellon (2008) defines carbon emissions factors for different industry sectors, as described by the United States Department of Commerce (Hendrickson et al., 2006). For these sectors the carbon emissions are provided for specific products, in million tonnes of CO_2 equivalent ($MtCO_2e$) emissions, per million Dollars of output produced from the related products. The mathematical modelling of the sectors considers flows and prices in the national economy as dictated by, for example, scarcity. The products in the EIO-LCA database were mapped against the product descriptions in the SARS database and the total CO_2e emissions were then assigned to the South African data based on the exported and imported Rand values. An exchange rate of R7.86 to US$1, as of April 2008, was used for the calculations (see Tables A3 and A4 in the Annexure).

Step 3: Addressing the uncertainties in the model-generated outputs

The assigned CO_2e emissions were verified against available national values for the key imported crude petroleum products and some of the export products, e.g. the platinum group of metals (PGMs), primary aluminium, and primary ferrochrome (as indicated in the tables of the Annexure). The verifications were based on available LCA calculations and studies, and company- and sector-specific reports. This verification process revealed the following:

- The import and export values are reasonably accurate and reliable as they are the basis for setting taxes; an uncertainty of 10 per cent was therefore assigned to these values.
- The assigned carbon emissions are highly uncertain since some of the EIO-LCA data are considerably different to available LCA and other data sources in South Africa; also exchange rate fluctuations would greatly influence the assigned carbon emissions per Rand value compared to a per Dollar value. For example, for the imported crude petroleum products, the EIO-LCA data indicates 2.15 $MtCO_2e$, but calculations for South Africa have shown a figure of 4.40 $MtCO_2e$ to be more accurate (see Table A3). For exported aluminium the EIO-LCA data assigns a figure of 8.2 $MtCO_2e$, but product-specific LCA studies have estimated a figure of 16 $MtCO_2e$ (Brent et al., 2001) (see Table A4). The discrepancies between these values are attributable to multiple factors, most notably the EIO-LCA model for the United States is not an accurate reflection of the carbon footprint associated with the South African economy. Furthermore, LCA related data for the South African industry has been found to be highly uncertain in general (Brent et al., 2002). Based on the verified and updated data an uncertainty of 50 per cent was therefore assigned to these values in general.

Step 4: Estimate the carbon balance while accounting for uncertainty

The uncertainties were used to obtain absolute minimum and maximum values for each of the parameters. Then Monte Carlo simulations that assumed normal distributions were utilised to account for fluctuations in the uncertainties and calculate standard deviations for the median values of the parameters. For risk assessments, where the underlying probability distributions are unknown, such an assumption has been shown to be reasonable (Hoffman & Hammonds, 1994). The standard deviations were then used to calculate minimum and maximum carbon import/export ratios. The minimum and maximum carbon emissions for the top twenty ranked products can then be determined (within a 95 per cent confidence interval) by multiplying these ratios by the actual import/export carbon values; as shown in equation (1):

$$C_{j,k} = c_{j,k} + r_{j,ave}\,.(1-p_j).V_3 \qquad (1)$$

where the minimum, average and maximum values are indexed by k; j is the index counter for whether the products are imports or exports; $C_{j,k}$ is the total estimated k of CO_2e emissions associated with j; $c_{j,k}$ is the total estimated k of CO_2e emissions associated with the top twenty ranked j; $r_{j,ave}$ is the average CO_2e emissions to imports/exports ratio obtained form Tables 3 and 4; p_j is the proportions of the total j values (as shown in Tables 1 and 2) made up by the top twenty ranked j; and V_j is the total j value as shown in Tables A1 and A2 of the Annexure. The values that were estimated using equation (1) are summarised in Tables 1 and 2.

Table 1

Calculated minimum and maximum CO_2e emissions for the top 20 imports (I)

Import ranking	Import value	Std dev.	CO_2e	Std dev.	Min CO_2e/I	Max CO_2e/I	Min CO_2e	Max CO_2e
	(billion Rand/yr)		(Mt/yr)		(t/R'000/yr)		(Mt/yr)	
1	76.85	4.43	4.40	1.26	0.04	0.08	2.99	6.03
2	40.47	2.34	4.08	1.18	0.07	0.14	2.75	5.59
3	31.04	1.78	2.48	0.71	0.05	0.11	1.67	3.39
4	22.81	1.32	4.53	1.30	0.13	0.27	3.06	6.20

5	17.53	1.01	0.67	0.19	0.03	0.05	0.45	0.92
6	10.50	0.61	0.53	0.15	0.03	0.07	0.36	0.72
7	9.84	0.57	0.79	0.23	0.05	0.11	0.53	1.07
8	8.57	0.50	0.73	0.21	0.06	0.12	0.50	1.01
9	8.25	0.48	0.47	0.14	0.04	0.08	0.32	0.64
10	7.82	0.45	0.79	0.23	0.07	0.14	0.53	1.08
11	7.05	0.41	2.42	0.69	0.23	0.47	1.63	3.31
12	6.42	0.37	0.38	0.11	0.04	0.08	0.25	0.51
13	6.37	0.37	0.40	0.12	0.04	0.08	0.26	0.54
14	4.75	0.27	1.28	0.37	0.18	0.37	0.87	1.76
15	4.45	0.26	0.22	0.06	0.03	0.07	0.15	0.31
16	3.96	0.23	0.27	0.08	0.04	0.09	0.18	0.36
17	3.52	0.20	0.41	0.12	0.08	0.16	0.28	0.57
18	3.31	0.19	0.36	0.10	0.07	0.15	0.24	0.49
19	3.23	0.19	0.15	0.04	0.03	0.06	0.10	0.21
20	2.97	0.17	0.30	0.09	0.07	0.14	0.20	0.41

Table 2

Calculated minimum and maximum CO_2e emissions for the top 20 exports (E)

Export ranking	Export value	Std dev.	CO_2e	Std dev.	Min CO_2e/E	Max CO_2e/E	Min CO_2e	Max CO_2e
	(billion Rand/yr)		(Mt/yr)		(t/R'000/yr)		(Mt/yr)	
1	69.04	3.99	28.28	8.16	0.28	0.56	19.16	38.86
2	39.94	2.29	16.36	4.75	0.27	0.56	10.97	22.37
3	25.70	1.48	19.47	5.60	0.51	1.04	13.17	26.66
4	23.68	1.37	12.11	3.49	0.34	0.70	8.14	16.55
5	22.63	1.31	1.73	0.49	0.05	0.10	1.13	2.32
6	18.52	1.08	1.48	0.43	0.05	0.11	1.00	2.05
7	17.53	1.01	6.02	1.73	0.23	0.47	4.06	8.23
8	12.93	0.75	3.62	1.03	0.19	0.38	2.47	4.97
9	11.34	0.65	2.58	0.75	0.15	0.31	1.71	3.51
10	11.31	0.65	16.00	4.67	0.94	1.94	10.68	21.88
11	11.24	0.65	4.22	1.21	0.25	0.51	2.85	5.78
12	9.05	0.52	0.72	0.20	0.05	0.11	0.47	0.95
13	7.57	0.43	1.50	0.43	0.13	0.27	1.01	2.05

14	6.34	0.37	0.64	0.17	0.07	0.14	0.45	0.87
15	4.27	0.25	0.82	0.23	0.14	0.27	0.59	1.15
16	4.11	0.24	0.74	0.23	0.12	0.25	0.49	1.03
17	3.93	0.22	0.71	0.20	0.12	0.24	0.47	0.95
18	3.82	0.22	0.30	0.08	0.05	0.11	0.21	0.41
19	3.29	0.19	0.30	0.08	0.06	0.12	0.21	0.41
20	3.04	0.18	0.77	0.23	0.16	0.34	0.50	1.04

Finally, the minimum, average, and maximum imported and exported carbon emissions and the total carbon emissions that are generated in South Africa, as reported by the International Energy Agency (IEA, 2006), were used in equation (2) to estimate the carbon balance for South Africa (see Table 3):

$$CI_n + CG = CE_m + CU \qquad (2)$$

where the minimum, average and maximum values for imports and exports are indexed by *n* and *m* respectively; CI_n is the total estimated *n* (minimum, average or maximum) of CO_2e emissions associated with imported products; *CG* is a constant value of CO_2e emissions generated in and released from the South African economy to produce products and services; CE_m is the total estimated *m* (minimum, average or maximum) of CO_2e emissions associated with exported products; and *CU* is a calculated value (to balance equation 2) of CO_2e emissions associated with products and services that are utilised within the South African economy.

Table 3
Estimated carbon balance for South Africa

Carbon balance (million tonnes)	Imported CO_2e		Internally generated[a]		Exported CO_2e		Internally utilised
Min I / Min E	35.35	+	386.66	=	105.88	+	316.13
Min I / Max E	35.35	+	386.66	=	188.19	+	233.82
Max I / Min E	53.14	+	386.66	=	105.88	+	333.92
Max I / Max E	53.14	+	386.66	=	188.19	+	251.62
Ave I / Ave E	**43.73**	**+**	**386.66**	**=**	**144.64**	**+**	**285.75**

[a] Reported by the International Energy Agency (IEA, 2006)

4
Discussion of the carbon balance outcomes

The nature of South Africa's economy from a carbon footprint perspective is interrogated using the data in Table 3 and estimating the ratios of imported and exported CO_2e emissions to: the internally generated CO_2e emissions; the internally utilised CO_2e emissions; and the exported and imported CO_2e emissions (Table 4).

For example, the total imported carbon is likely to be less than 14 per cent of the total internally generated CO_2e, and is also less than 21 per cent of the internally utilised CO_2e, within the South African economy. And, on average, the total imported carbon is approximately a third of the total exported carbon. Expressed another way, the exported carbon is at least twice as much as the carbon imported. Furthermore, when compared to the total carbon generated within the South African economy, on average about a third is exported. However, it is noteworthy that this value could exceed 50 per cent of the carbon associated with products and services utilised internally in the South African economy (Table 4).

Table 4

Calculated ratios from the carbon balance

Ratio of imported CO_2e to:	Minimum	Maximum	Average
Internally generated CO_2e	0.09	0.14	0.11
Exported CO_2e	0.19	0.50	0.30
Internally utilised CO_2e	0.11	0.21	0.15
Ratio of exported CO_2e to:	**Minimum**	**Maximum**	**Average**
Internally generated CO_2e	0.27	0.49	0.37
Imported CO_2e	1.99	5.32	3.31
Internally utilised CO_2e	0.32	0.80	0.51

It is interesting to compare these ratios with another rapidly developing country such as Brazil. Machado et al. (2001) report that Brazil is a net exporter of carbon with the inflows and outflows of embodied carbon equating to 10 per cent and 14 per cent of the total carbon emissions of the Brazilian economy, respectively; the comparable (average) numbers of South Africa are 11 per cent and 37 per cent. In Brazil 56 per cent more carbon is associated with a dollar earned with exports than a dollar spent on imports. For South Africa this number is a minimum of 129 per cent, if utilising the maximum imported CO_2e (R453.60 billion spent) and the minimum exported CO_2e (R393.04 billion earned). It is therefore undeniable that South Africa's economy is not only extremely carbon-intensive, but it is also a major exporter of this carbon.

Additional evidence of South Africa's carbon-intensity are the mining sector and its associated value-addition manufacturing activities, which contribute around 5 per cent and 16 per cent of South Africa's GDP, respectively (StatsSA, 2008). In this study it is estimated (from Tables A4 and 3) that at least 74 per cent of the exported carbon is attributable to these two economic activities, namely mining and primary manufacturing. The amount of exported carbon from these activities is more than 27 per cent of the internally generated carbon of the country. This profile is comparable to other developing countries with large mining sectors. For example, the exports of copper account for approximately 15 per cent of the Chilean GDP (Anderson, 2004). It is estimated (from Velasco, 2000; Kuckshinrichs et al., 2007; IEA, 2005) that the carbon embodied in these exports is in the order of 25 per cent of the internally generated carbon of the Chilean economy.

5 Policy interventions to influence the carbon balance of South Africa

5.1 South Africa's Grand Challenge – maintaining economic growth while remaining competitive in a future carbon-constrained global economy

To have even a 50 per cent chance of making a stabilization target of a 2°C global temperature increase[5], the IPCC (2007) estimates that global emissions will have to peak by 2015, and be reduced by between 50 and 85 per cent of 2000 levels by 2050. In line with this, South Africa's Climate Change Strategy sets out to achieve a reduction in the rate of increase in its GHG emissions by between 2020 and 2025, then to stabilise the emissions for ten years, and then to reduce the emissions in absolute terms from between 2030 and 2035 onwards. The strategy will result in South Africa emitting 100 million tonnes of GHG above its 2003 level to reach a ceiling of 550 million tonnes by 2025.

The strategy responds to internationally sanctioned limitations on GHG emissions that are likely to become stricter and will be increasingly enforced across the world (de Boer, 2008; Jackson, 2008; Beunderman, 2008). A consequence of these stricter international requirements is that they will make imports with large associated carbon footprints uncompetitive. Low-carbon products will be preferred because international buyers will be subjected to substantial carbon taxes – likely to exceed the existing €18.7 per tonne of CO_2e being paid in the European Union Emissions Trading Scheme (PointCarbon, December 2008) – when importing high-carbon products into those countries. This is likely to negatively impact on the South African mining and manufacturing sectors that rely on export markets. An example is the manufacturing of aluminium. Manufacturing of primary aluminium in Iceland may be preferred in European markets, because the carbon footprint of the Iceland aluminium ingots is in the order of a third of that of the South Africa ingots, based on international life cycle analyses (IAI, 2007), due to renewable energy resources being used in that country.

South Africa's grand challenge therefore is to decouple its economic growth from carbon emissions in order to remain competitive in a future carbon-constrained global economy and to ensure it meets its socio-economic targets of halving poverty, to less than one-sixth of households, and unemployment, to below 15 per cent, by 2014 (Republic of South Africa, 2006).

5.2 Approaches to decouple growth in South Africa's mining and manufacturing sectors from greenhouse gas emissions (GHGs)

There are three main approaches that South Africa could pursue to help ensure it meets this challenge:

1. Increase the beneficiation of mineral resources in ways that generate domestic economic activity and employment while reducing associated GHG emissions.

   The South African government has recognised the need to increase the beneficiation of mineral resources to increase the value of exports, stimulate economic growth, and provide employment (DME, 2008a). However, the implications of this on the carbon balance depend on the manner in which this beneficiation is done. Beneficiation of metal ores to a metal, for example, is energy intensive and will lead to an increase in the carbon footprints of exported products due to the coal-based nature of South Africa's energy supply. For example, the carbon footprint of ferro-alloy products is more than five times that of the iron raw material, on a total CO_2e export basis, and a factor of two, on an export value basis (see Table A4). But, the further beneficiation of the metals to metal products is less energy intensive and will reduce the carbon footprint of South African exports. Examples are the iron, stainless steel and aluminium *products* in Table A4. Therefore, given the energy and carbon intensity of the South African economy, it would seem that government policy should focus on expanding its production and export of metal products instead of ores and metals only.

2. Increase the efficiency with which energy is supplied and used in the South African mining and manufacturing sectors.

   The South African government approved an energy efficiency strategy that sets the target for improved energy efficiency in South Africa at 12 per cent by 2015 (DME, 2005). Much of these efforts should be directed to the metals beneficiation sector, where new technological interventions may result in substantial carbon footprint improvements. An example is the ferrochrome industry, where new technologies could reduce the energy intensity per tonne produced by as much as 40 per cent (Naicker & Riley, 2006). Therefore, government policy should focus on incentivising such technological interventions in the South African metal product value chain.

3. Diversify South Africa's energy sources, primarily towards increasing the contribution of nuclear and solar energy.

   The South African white paper on renewable energy has set a target of 10 000 GWh of energy to be produced from renewable energy sources, mainly from biomass, wind, solar and small-scale hydro, by 2013 (DME, 2003). In addition, the South African government has introduced a nuclear policy (DME, 2008b). The policy, and associated strategy, is seen as key to the government's climate response plans that follow on South Africa's "long-term mitigation scenarios" (LTMS) study (Scenario Building Team, 2007); the aim is that half of the new electricity generation, or 20 000 MW, must be based on nuclear resources by 2025 (Creamer, 2008a). Increased feed-in tariffs are also on the horizon to support an increased diversity of energy supply (van der Merwe, 2008), and policy interventions should be considered to extend this diversity even further.

The relative effectiveness, efficiency and equity of each of these approaches will vary depending on their objectives (economic, social or environmental), design, and date of implementation. The optimal mix of the approaches therefore needs to be urgently assessed based on how well they contribute to fulfilling government's socio-economic goals and longer-term environmental criteria. Also, the appropriate mix of policies for facilitating the implementation of any one or more of these approaches is not immediately obvious. Therefore, the policies being developed and implemented to decarbonise economies elsewhere in the world (Stern, 2006) should be considered in the South African context.

5.3 Broad policy interventions to facilitate South Africa's move towards a decarbonised economy

Three broad policy interventions are required for South Africa to remain competitive on the international scene and to make a meaningful contribution towards climate-change mitigation, and, in so doing, meet its ethical responsibilities. These three policy approaches need to address entire production and consumption value chains in the economy, namely, begin-of-pipe interventions, transformation process interventions, and end-of-pipe interventions; and involve:

1. Ensuring the social costs of GHG emissions are included in economic decision making of such interventions through quantity- (cap-and-trade) and/or price- (taxes) based mechanisms and standards;
2. Removing barriers to investment in value-addition activities (primarily the production of metal-products), low-carbon energy sources, and energy-efficient technologies, through free-trade negotiations, i.e. Doha Round, subsidies and/or tax-breaks, good governance, and reducing risk and uncertainty for such investments; and
3. Promoting behavioural changes by providing information and easier access to finance and markets.

Appropriate design and early implementation are pivotal factors that will drive the effectiveness of each of these policies. Incentive-based mechanisms such as taxes, subsidies, cap-and-trade, and hybrid tax-and-trading systems are promoted as more efficient and effective ways to meet environmental goals compared with traditional command-and-control approaches (Fisher et al., 1995; Stern, 2006). These are promoted because theory indicates that they create real financial reasons to mitigate emissions, i.e. lower abatement costs, while providing flexibility on how to do so and stimulating innovation (Kolstad and Toman, 2001). Initial indications are that the South African Government[6] is leaning towards the introduction of price-based mechanisms, i.e. carbon taxes and clean-technology subsidies/tax breaks, instead of quantity-based mechanisms, i.e. carbon trading (Ensor, 2008), but no evaluation and assessment of the context-specific factors that determine their respective strengths and weaknesses has yet been undertaken.

The delays in evaluating and selecting appropriate policies are due to numerous factors:

- the lack of a clear, long-term, global policy framework within which to work;

- a lack of clarity and understanding of the obstacles and the opportunities (i.e. potential for profitable investment) to clean-energy investment and increased beneficiation;
- the lack of sufficient accurate and reliable data relating to the quantities of emissions, and the costs and benefits of abatement;
- insufficient understanding about the risks, uncertainties and tradeoffs associated with these issues; and
- limited capacity/capability and expertise on how to quantify uncertainties and tradeoffs, evaluate the beneficiation opportunities and policy options, and how to implement these.

5.4 Further research requirements

Urgent and directed research efforts are required to address these issues. A research agenda with the following key components is therefore proposed:

1. Undertake a diagnostic study (gap analysis) to:
    a. Identify the opportunities and constraints to increased beneficiation in the mining and manufacturing sectors of the South African economy, and to public/private investments in clean-energy technology.
    b. Assess the information, data and modelling capabilities that are available and what is required.
2. Refine an economic input-output model for South Africa.
3. Develop appropriate data monitoring, collecting, and collating capabilities (i.e., equipment, processes, databases) and access protocols.
4. Develop and calibrate integrated assessment models for South Africa and the southern African region that will allow for context-specific policies to be evaluated to better inform government.

6 Conclusions

The outcome of the carbon balance study highlights the energy and carbon intensity of the South African economy and specifically its exports. The study also emphasises the requirement of an appropriate government policy mix that supports increased value addition within the economy, whilst also providing incentives for all stakeholders in the South African economy to decrease the carbon footprints associated with all production and consumption processes. Specifically, the opportunity is identified to reduce the South African export carbon footprint by placing an emphasis on beneficiation beyond refined metals to end products, e.g. South Africa should not export steel, but steel products; not platinum, but exhaust catalysts and jewellery. In terms of the latter there is a need for government to address the import tariffs that many developed countries still pose on South African products from platinum. Furthermore, the diversification of the South African electricity mix, and a focus on energy efficiencies in the heavy industry sector, are essential if the carbon footprints of the country's products are to be reduced. This will become increasingly important as international limitations will become stricter and binding, and developed countries will either not buy South African less-beneficiated high-carbon products or will demand discounts, in order to cover the taxes they may face for importing South African carbon.

To facilitate an economic transition, the paper describes a number of challenging policy issues that require urgent attention in order to remove uncertainty in decision making and to prevent South Africa from committing to a high-carbon, and possible extremely costly, future. An economics research agenda is therefore proposed for the South African scientific, policy and business communities that lead to earlier and better decision making through improved understanding and collaborative engagement of all stakeholders. Principally, the research should focus on disseminating environmental information and building transdisciplinary capabilities, economic input-output (and other) modelling, policy assessment, risk/uncertainty analyses, and improving understanding of behavioural responses to various policy mixes. And finally, the urgency of this research needs to be re-emphasised, because delays in defining clear, long-term energy and climate policy frameworks are setting South Africa on a high carbon-emissions trajectory, which is likely to result in substantial social and economic costs in the not too distant future.

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Endnotes

1 Mukhopadhyay and Chakraborty (2005b) describe the conflicting Pollution Haven and the Factor Endowment Hypotheses (PHH and FEH, respectively) that economists and environmentalists continue to debate.

2 The terms ‘embodied carbon’ and ‘carbon footprint’ are used interchangeably in this paper and refer to the greenhouse gases (GHGs) emitted at all stages of a good’s manufacturing process, from the mining of raw materials through the distribution process, to the final product provided to the consumer (Kejun et al., 2008).

3 Carbon dioxide equivalency is a quantity that describes, for a given mixture and amount of greenhouse gas, the amount of CO2 that would have the same global warming potential (GWP), when measured over a specified timescale (generally, 100 years). Carbon dioxide equivalency thus reflects the time-integrated radiative forcing, rather than the instantaneous value described by CO_2e

4 The top 20 prioritised imports account for 61.7 per cent, and the top 100 imports account for 86.2 per cent of the total import value. The top 20 prioritised exports account for 78.7 per cent, and the top 100 exports account for 96.5 per cent of the total export value.

5 Missing the 2°C target is seen by many to be courting disaster that extends beyond the environmental and could lead to intolerable impacts on human well-being, in spite of all feasible attempts at adaptation (IPCC, 2007).

6 The South African government recently adopted an ambitious Climate Change Policy Framework that includes the consideration of market mechanisms to curb climate change (Creamer, 2008b), which is in line with National Treasury’s (2006) investigations into environmental fiscal reform, specifically environmental-related taxes and charges, to support sustainable development.

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Annexure

Table A1
The top twenty imports of the South African economy prioritised based on their economic values (2007 ZAR billion per year)

Import ranking	Generic description* of products	Tariff group	Import value (bR/yr)	Import quantity	Units per year
1	Crude petroleum products	27090000	76.85	22.09[a]	million tonnes
2	Original equipment components	98010000	40.47	626.47	million units
3	Automotive products	87030000	31.04	0.34	million units
4	Refined petroleum products	27100000	22.81	4.74	million tonnes
5	Telephone sets/equipment	85170000	17.53	19.20	million units
6	Data processing equipment	84710000	10.50	14.47	million units
7	Road transportation products (other)	87040000	9.84	0.08	million units
8	Earth moving equipment	84290000	8.57	0.01	million units
9	Pharmaceutical products	30040000	8.25	0.04	million tonnes
10	Transportation sub-components	87080000	7.82	1619.00	million units
11	Mineral commodities (other)	71020000	7.05	1.37	million carrats
12	Air transportation products	88020000	6.42	0.002	million units
13	Printing products/equipment	84430000	6.37	12.91	million units
14	Paint-related chemicals	28180000	4.75	1.76	million tonnes
15	Accessories (other)	84730000	4.45	85.82	million units
16	Turbine products/equipment	84110000	3.96	0.30	million units
17	Tyre products	40110000	3.52	6.28	million units
18	Audio/visual storage products	85230000	3.31	362.60	million units
19	Minor medical products/equipment	90180000	3.23	275.98	million units
20	Minor production sub-components	84310000	2.97	462.47	million units
		Total imports	**453.60**	**billion Rands**	
		Percentage of total imports	**61.7**	**%**	

* A detailed description of each of these products is available from SARS (2008) and StatsSA (1993)

[a] Verified with the energy statistics of the South African Department of Minerals and Energy (DME), available from http://www.dme.gov.za/energy/statistics.stm

Table A2
The top twenty exports of the South African economy prioritised based on their economic values (2007 ZAR billion per year)

Export ranking	Generic description* of products	Tariff group	Export value (bR/yr)	Export quantity	Units
1	Platinum Group of Metals (PGM)	71100000	69.04	0.32[a]	kilo tonnes
2	Gold commodity	71080000	39.94	0.30	kilo tonnes
3	Ferro-alloy products	72020000	25.70	4870.00[b]	kilo tonnes
4	Coal-related products	27010000	23.68	68730.0	kilo tonnes
5	Processing equipment	84210000	22.63	31.43	kilo units
6	Automotive products	87030000	18.52	143.93	kilo units
7	Mineral commodities (other)	71020000	17.53	21470.0	kilo carats
8	Crude petroleum products	27090000	12.93	3720.00	kilo tonnes
9	Stainless steel products	72200000	11.34	502.72	kilo tonnes
10	Aluminium commodity	76010000	11.31	870.00[c]	kilo tonnes
11	Iron commodity/concentrate	26010000	11.24	31550.0	kilo tonnes
12	Transportation products (other)	87040000	9.05	357.72	kilo units
13	Refined petroleum products	27100000	7.57	1570.00	kilo tonnes
14	Transportation sub-components	87080000	6.34	105880.0	kilo units
15	Citrus fruit products	8050000	4.27	1480.00	kilo tonnes
16	Iron products	72080000	4.11	970.00	kilo tonnes
17	Chromium commodity/concentrate	26100000	3.93	3940.00	kilo tonnes
18	Precious metals by-products	71120000	3.82	2.56	kilo tonnes
19	Precious metals/concentrate	26160000	3.29	0.98	kilo tonnes
20	Aluminium products	76060000	3.04	120.00	kilo tonnes
		Total exports	**393.04**	**billion Rands**	
		Percentage of total exports	**78.7**	**%**	

* A detailed description of each of these products is available from SARS (2008) and StatsSA (1993)

[a] Updated from the Johnson Matthey PGM market review: Platinum 2008, available from http://www.platinum.matthey.com/publications/Pt2008.html

[b] Updated from the South African Department of Minerals and Energy (DME) report number R52/2006: South African production trends 1995 – 2004, available from http://www.dme.gov.za/minerals/documents.stm

[c] Updated from the statistical data of the Aluminium Federation of South Africa (AFSA), available from: http://www.afsa.org.za/

Table A3

Assigned carbon emissions (tonnes of CO_2e) to the top twenty ranked imports based on their total economic values (2007 ZAR)

Import ranking	Generic description of products	CO_2e (Mt/yr)	CO_2/import (t/R'000)	CO_2/import (approx.)	Units
1	Crude petroleum products	4.40[a]	0.06	0.20	t/t
2	Original equipment components	4.08	0.10	6.52	kg/t
3	Automotive products	2.48	0.08	7.32	t/unit
4	Refined petroleum products	4.53	0.20	0.96	t/t
5	Telephone sets/equipment	0.67	0.04	0.03	t/unit
6	Data processing equipment	0.53	0.05	0.04	t/unit
7	Road transportation products (other)	0.79	0.08	10.06	t/unit
8	Earth moving equipment	0.73	0.09	59.60	t/unit
9	Pharmaceutical products	0.47	0.06	12.91	t/t
10	Transportation sub-components	0.79	0.10	0.49	kg/unit
11	Mineral commodities (other)	2.42	0.34	1.77	t/carrat
12	Air transportation products	0.38	0.06	172.99	t/unit
13	Printing products/equipment	0.40	0.06	0.03	t/t
14	Paint-related chemicals	1.28	0.27	0.73	t/t
15	Accessories (other)	0.22	0.05	2.62	kg/t
16	Turbine products/equipment	0.27	0.07	0.88	t/unit
17	Tyre products	0.41	0.12	0.07	t/unit
18	Audio/visual storage products	0.36	0.11	0.98	kg/unit
19	Minor medical products/equipment	0.15	0.05	0.54	kg/unit
20	Minor production sub-components	0.30	0.10	0.65	kg/unit

[a] More accurate carbon emission data was obtained from PE International LCA calculations, contact Dr Johannes Gediga (j.gediga@pe-international.com)

Table A4
Assigned carbon emissions (tonnes of CO_2e) to the top twenty ranked exports based on their total economic values (2007 ZAR)

Export ranking	Generic description of products	CO_2 eq. (Mt/yr)	CO_2/export (t/R'000)	CO_2/export (approx.)	Units
1	PGM commodities/products	28.28[a]	0.41	87.83	kt/t
2	Gold commodity	16.36	0.41	54.23	kt/t
3	Ferro-alloy products	19.47[b]	0.76	4.00	t/t
4	Coal-related products	12.11	0.51	0.18	t/t
5	Processing equipment	1.73	0.08	55.04	t/unit
6	Automotive products	1.48	0.08	10.28	t/unit
7	Mineral commodities (other)	6.02	0.34	0.28	t/carrat
8	Crude petroleum products	3.62	0.28	1.19	t/t
9	Stainless steel products	2.58	0.23	5.14	t/t
10	Aluminium commodity	16.00[c]	1.42	18.39	t/t
11	Iron commodity/concentrate	4.22	0.38	0.13	t/t
12	Transportation products (other)	0.72	0.08	2.02	t/unit
13	Refined petroleum products	1.50	0.20	0.74	t/t
14	Transportation sub-components	0.64	0.10	6.04	kg/unit
15	Citrus fruit products	0.82	0.19	0.55	t/t
16	Iron products	0.74	0.18	0.76	t/t
17	Chromium commodity/concentrate	0.71	0.18	0.18	t/t
18	Precious metals by-products	0.30	0.08	0.12	kt/t
19	Precious metals/concentrate	0.30	0.09	0.30	kt/t
20	Aluminium products	0.77	0.25	6.62	t/t

[a] More accurate carbon emission data was obtained from a LCA study that was conducted for Lonmin Platinum, available from: http://www.lonmin.com

[b] More accurate carbon emission data was obtained from CSIR LCA calculations (Raghubir et al.., 2000)

[c] More accurate carbon emission data was obtained from a CSIR LCA study (Brent et al.., 2001)