Status and prospects of life-cycle assessments, carbon- and water footprinting studies in South Africa

Kevin G. Harding[a*], Elena Friedrich[b], Henry Jordaan[c], Betsie le Roux[d], Philippa Notten[e], Valentina Russo[f], Nydia Suppen-Reynaga[g], Michael van der Laan[d], Taahira Goga[a]

[a]*Industrial and Mining Water Research Unit, School of Chemical and Metallurgical Engineering, University of the Witwatersrand, Johannesburg, South Africa (kevin.harding@wits.ac.za)*

[b]*Civil Engineering Programme, University of KwaZulu-Natal (friedriche@ukzn.ac.za)*

[c]*Department of Agricultural Economics, University of the Free State (jordaanh@ufs.ac.za)*

[d]*Department of Plant and Soil Sciences, University of Pretoria (Michael.vanderlaan@up.ac.za)*

[e]*The Green House (pippa@tgh.co.za)*

[f]*Department of Chemical Engineering, Environmental & Processing Engineering Research Group, University of Cape Town (valentina.russo@uct.ac.za)*

[g]*Center for LCA and Sustainable Design (nsuppen@centroacv.mx)*

ORCID:

Harding: 0000-0003-2708-4323

Friedrich: 0000-0003-1023-3054

Jordaan: 0000-0003-4845-1727

le Roux: 0000-0002-2079-5539

Notten: 0000-003-1023-3054

Russo: 0000-0001-8691-4193

van der Laan: 0000-00018656-623X

Goga: 0000-0002-4990-6669

Abstract

Purpose Using the current state of life-cycle assessment (LCA), carbon-, water footprinting, and EPDs in South Africa, this work explores the challenges and opportunities for scholarly development in these areas in the country.

Methods Being a relatively small LCA community in South Africa, academics, consultants, and other stakeholders were approached to provide lists of known studies, with further reports, that may have been missed, obtained through internet searches. Information was collated on database development, capacity building, and other aspects and presented here in a single paper.

Results and Discussion While the authors are aware of companies working on LCA and related studies, hidden in confidential reports, we were able to find 27 LCA, 17 water-, 12 carbon footprinting, and 10 EPD studies. Although these studies have potential advantages for policymaking and business, their number, implementation, and impact remain limited.

Conclusion While previously seen as an academic exercise, life-cycle thinking has been adopted by industry, private consultants, and the South African National Cleaner Production Centre (NCPC-SA), amongst others. Growing interest has led to the creation of several training courses available at academic institutes, the NCPC-SA, and consulting firms, ranging from basic understanding to advanced use of software packages and modeling techniques. The development of a national LCI database, and further exposure and opportunity for LCA studies, are important steps to hopefully spur LCA in southern Africa in the future.

Keywords: South Africa; Life-cycle assessment; Water footprint; Carbon footprint; Sustainability

1. Introduction

1.1. South Africa as a country

South Africa is located on the southern tip of the African continent covering an area of 1 219 090 km^2 (CIA Factbook 2020), with a population estimated at 57.7 million as of 1 July 2018 (Statistics South Africa 2018). The economy ranked 35th in the world and 2nd in Africa with a Gross Domestic Product (GDP) of USD 317 568 billion in 2017 (WorldAtlas 2017). The World Bank puts the country in the category of upper-middle-economy countries making it one of only four countries in this category on the continent. Traditionally, the primary and secondary sectors of the South African economy include agriculture, mining, and manufacturing, with tertiary sectors including finance, business, trade, government, transport, and personal services (WorldAtlas 2017).

1.2. Sustainable development and environmental challenges in the local context

In 1992, the United Nations Conference on Environment and Development (UNCED) signaled the increasing focus on environmental matters in the context of political and business decision making. One of the calls was for national governments to report local environmental data. South Africa produced two key reports ('National State of the Environment' and the 'South Africa Environment Outlook') in 1999 and 2006 respectively, with updates to the 'South Africa Environmental Outlook' report in 2012 and 2018. The National Development Plan has also stated that environmental impacts are an integral part of the country's development agenda (National Planning Commission 2012). Other more specific environmental information is available through detailed reports, such as the "National Biodiversity Assessment" reports, "Greenhouse Gas Inventory" reports, "Environmental Sustainability Indicators", and more (https://www.environment.gov.za/otherdocuments/reports and http://soer.environment.gov.za/soer/.

The challenge for South Africa is to limit environmental impacts in the context of a growing population and increased urbanization around a few South African urban nodes (The World Bank 2018). Historically, this has led to a loss of natural habitat, increased pollution, and declining environmental quality. This rapid urbanization process, and other factors, were seen as drivers to the process which gave rise to one of the most unequal societies in the world (The World Bank 2018). In terms of implications for the environment, it means that the country faces mass consumption (increased consumerism and associated resource use and waste generation) from a limited upper class and an increasing middle class, as well as consequences due to citizens living in abject poverty. Additionally, the country still has a strong dependence on coal-based energy, resulting in high air pollution.

Therefore, quantitative tools such as LCAs, carbon- and water footprints are becoming more important, not only as process tools but also as a source of environmental indicators.

1.3. Problem statement and objectives of the study

In the past 20 years, public awareness surrounding sustainable development has grown, as has the number of LCA studies, as can be seen through various country-specific review studies (Croft et al.; Chen et al. 2014; Hou et al. 2015; Estrela 2015; Zanghelini et al. 2016; Maepa et al. 2017; Burman et al. 2018; Engelbrecht et al. 2018; Bodunrin et al. 2018; Wiloso et al. 2019; Ladenika et al. 2019). In South Africa, environmental performance has become increasingly significant in the context of escalating sustainable economic growth and development. This has led to an increase in the use of quantitative environmental assessment tools such as LCAs. This paper presents an overview of the implementation and utilization of LCA-related assessments in South Africa over the period 2011-2019. While there are several assessment methods available, the focus is limited to LCA, water-, and carbon footprint studies as well as environmental product declarations (EPD) as the core tools. Studies that utilized assessment methods such as eco-efficiency, social-LCA, or other qualitative assessments, were excluded due to the limited number of local studies published. This work further summarizes the country's involvement in the Sustainable Recycling Industries (SRI) program (SRI 2020) in South Africa. From the findings, the paper explores challenges and opportunities for LCA developments in South Africa.

2. Methodology

Members from the South Africa LCA community, through formal collaborations, informal networks, mailing lists, as well as participation at yearly LCA workshops, were approached in person, or via email to provide information regarding existing LCA-related studies (LCA, water- and carbon footprint studies) that they had produced, or knew of in their extended networks. These included research organizations, academic institutions, and environmental consulting companies. Additional studies were identified through internet searches (Google/Google Scholar and Scopus) using combinations of the terms 'life-cycle assessment', 'carbon footprint', 'water footprint', and 'South Africa'. Additionally, environmental product declarations (EPDs) were included for an additional perspective on environmental awareness in the country. This study further reports on the LCI data collection activities in South Africa (through the Sustainable Recycling Industries program). Within the SRI program (SRI 2020), South Africa has developed several LCI datasets, and at the same time organized capacity-building workshops across the country. The challenges and opportunities this have shown are also given.

The results presented in this paper are restricted to studies published during the period 2011-2019. For a prior snapshot of the status of LCA in South Africa, the paper by Brent and colleagues is recommended (Brent et al. 2002). Studies that are based on lifecycle thinking, such as life-cycle management, life-cycle costing, and social life-cycle assessment were excluded due to the relatively small number of published studies reported for South Africa. Studies where reports were not available online, nor published in (open access or subscription) journals, were excluded, e.g. studies from private consulting projects, since rigor and findings could not be validated. Studies with a scope specifically outside the borders of South Africa, even if the work was co-authored by South Africans, were also excluded. Research studies leading to academic degrees were not included, except for the peer-reviewed outputs of these degrees. Database results that are available in LCA software packages were also not included in this study e.g. in openLCA Nexus, which lists 14 865 data sets for South Africa, including potential duplicates of unit vs system processes and consequential vs cutoff scenarios (GreenDelta GmbH 2019).

3. Results and Discussion

LCA, carbon- and water footprinting studies, as well as EPDs available addressing South African cases, are presented (Figure 1).

3.1. Life-cycle assessment (LCA)

For the period 2011-2019, a total of 27 publicly available LCA studies were reported (Table 1). Nine studies were published between 2011 and 2014 while the remainder were published after this period. Fifteen out of 27 studies were available in peer-reviewed journals, while ten were available as research reports, and two as full conference papers. It should be noted that conference papers or abstracts that later became full journal papers were not included to avoid double counting.

Eight studies were for the agricultural sector, which included assessments of dairy, livestock, and crop products and processes. Furthermore, seven studies centered on the energy industry, including activities such as biofuel and biogas production. Three studies were conducted for the mining sector focusing on the environmental impacts of the mining process of Platinum Group Metals (PGMs) and sandstone. LCA studies were also conducted for the value chains of certain textile products such as t-shirts and towels. Other studies were conducted for the infrastructure, water, and packaging sectors (Figure 2). The share of LCA studies in the manufacturing (38%) and agriculture (31%) sectors do not correspond to their contribution to the South African GDP (13 and 1%

respectively), which is dominated by financial services, government, and trade (20-, 18 and 17% respectively) (Statistics South Africa 2020). It is noted that the GDP figures change from quarter to quarter, and the impact of COVID could play a role in future numbers. Given that most progress has been made, and more experiences exist for 'product' LCAs, it is understandable that there are substantial gaps in the tertiary sector, to address financial services and trade, which contribute significantly to the country's GDP. GDP figures for trade also relate to other sectors of the GDP through, for example, manufacturing and agricultural products, such that the representation here may not be completely accurate based purely on GDP values.

Only three out of 27 these studies were initiated and funded by government research organizations. The rest were supported by private companies and professional associations with strong international links. Therefore, it appears that the drivers for LCAs are mainly from industry (with some international motivation due to exports) and less from government entities.

3.2. Water footprinting

Seventeen water footprint studies have been conducted in South Africa between 2012 and 2019 (Table 2). Between 2012 and 2017, published water footprint research has increased annually with 43% of studies being published in 2017. Only one study was published in 2012 and 2013, respectively. Most water footprint studies (76%) were for the agricultural industry, with eight studies on vegetables and fruits and one on wheat production for bread. Four studies were conducted on livestock production of which three studies were in terms of dairy production and one study on beef. Three water footprint studies were done for processes in the mining industry. A single study was conducted for water management purposes. No water footprint studies were found for any other industries, such as forestry, energy, waste, and textile industries.

In 2019, 62% of the freshwater water resources in South Africa were used by the agricultural sector, 27% by municipalities, 3% by industries, 3% by mining activities, and 2% each by forestry and energy sectors. This breakdown of water use is mirrored in the number of water footprint studies, with most of them in the agricultural sector, followed by water footprint studies in industries and mining activities (Figure 3). It has to be stated that the country is deemed as water-scarce, with extreme rainfall variations and uneven geographical distribution of water resources (GreenCape 2019). Also, severe droughts have been recorded and current water usage exceeds reliable water supply in some areas.

The majority (78%) of water footprints used the Hoekstra methodology (Hoekstra et al. 2011). Two studies (presented as a publication, thesis, and technical report) compared the applicability of the Hoekstra method(Hoekstra et al. 2011) versus a regional water stress index approach (Milà I Canals et al. 2009; Pfister et al. 2009; Ridoutt and Pfister 2010) and a hydrologically-based method (Deurer et al. 2011). It should be noted that six of the 17 studies were funded by the government through the Water Research Commission of South Africa (WRC) and centered around crops or value chain goods. Industry is linked to six of the 17 studies and catchment management agencies and regional organizations are associated with eight studies.

Therefore, the drivers for water footprint studies appear to differ from the drivers for LCAs. Water footprints are connected mainly to government research organizations, such as the Water Research Commission, who provide more funding than the private sector to academic institutes and consulting firms.

3.3. Carbon footprinting

Twelve academic, peer-reviewed carbon footprinting studies were reported (Table 3). Most of the studies (seven) were centered on the agricultural sector, with research conducted for vegetable and fruit crops, sugarcane, wine, and livestock. Two studies were undertaken for the mining process of platinum group metals. Although private companies conduct their carbon footprint studies and publish the results in annual sustainability reports, these were not included in this paper since different quality control and review procedures were used, hence no validation was possible. In this context, the Carbon Disclosure Project (CDP), adopted through the National Business Initiative (partnered with the World Business Council for Sustainable Development (WBCSD)), needs to be mentioned. In 2010, this initiative resulted in the publication of carbon footprint information for 100 companies from different sectors listed on the Johannesburg Stock Exchange (CPD - Carbon Disclosure Project 2011). However, this initiative has not been updated and most figures for the carbon footprints will be outdated.

An analysis of the distribution of published carbon footprints per sector in South Africa shows no correspondence with their levels of contribution to the GDP. (Figure 4). The latest GHG inventory for South Africa (2012) showed that the energy sector is a significant contributor to carbon dioxide and other emissions with a 67.8% allocation. Other sectors such as industry, transport, 'agriculture, forestry, and other land use' (AFOLU) and waste contributed with 12.8%, 9.2%, 6%, and 4.2%, respectively (Department of Environmental Affairs 2018). None of the academic carbon footprint studies published in the last few years have investigated the highest emitting sectors in the country. The energy and transport sectors are dominated by government-controlled parastatal companies (i.e. Eskom, Transnet, and Sanral) and this highlights the need for detailed, consistent peer-reviewed carbon footprints not only in the private sector but more importantly for government parastatals.

From the experience of the authors, there are many carbon footprinting studies conducted for internal use. The drivers in these studies are thus either for internal company consumption or from a business perspective, rather than at a basic research level, as seen in the reports listed in the Johannesburg Stock Exchange.

3.4. Environmental Product Declarations (EPD)

EPDs present quantified environmental information on the life cycle of a product and are based on independently verified LCA data (International Organization of Standardization (ISO) 2006). Since 2016, ten EPDs have been published. Belgotex Floors has three EPDs registered in the Global Green Tag EPD program; the LCA studies considered the production of carpets and other flooring applications in Pietermaritzburg, South Africa in 2014 (Belgotex Floors 2016a, b, c). Chevron Crushtech, a supplier of post-consumer recycled filling and building sands, also registered EPDs in the Global Green Tag. There is one EPD for building sand (Blu-Core Building Sand) and three for fillings (Blu-Core G5, G6, and G7 filling) where the LCA considered applications in industrial sectors and the 2017 production in South Africa (Chevron Crushtech 2018a, b, c, d). Five more EPDs from Gyproc Saint Gobain were found in the International EPD System, showing the results of the LCA studies of their Rhinoboard products, a calcium sulfate-based material to build drywall and/or ceilings. Data for these EPDs was collected from the production site in Cape Town for the year 2016 and in Brakpan for the year 2017 (Gyproc Saint Gobain 2018a, b, 2019). While the exact drivers for EPDs are not clear, their number and awareness about these are both increasing.

3.5. LCI data collection and local expertise projects: Sustainable Recycling Industries (SRI) program and REAL project

The Sustainable Recycling Industries (SRI) program was funded by the Swiss State Secretariat for Economic Affairs (SECO) and jointly implemented by the Swiss Federal Laboratories for Materials Science and Technology (EMPA), the World Resources Forum (WRF), and the ecoinvent Association. The SRI Component A, coordinated by ecoinvent, aimed at building LCA/LCI expertise through training events, and at building life-cycle inventory (LCI) data (industrial, agricultural, and other sectors) for newly industrialized countries, including

Brazil, India, and South Africa. The creation of reliable, consistent, and transparent regionalized LCIs represented a core purpose of the SRI program Component A.

The SRI Component A was constructed on three pillars:

- Setting up regional LC networks;
- Developing local LCI/LCA expertise; and
- Building LCI datasets.

UNEP's LCInitiative, together with the ecoinvent Association and the European Commission, developed a program to promote national databases. The 'Resource Efficiency through Application of Life cycle thinking' (REAL) project, which included South Africa, ran from October 2018 to August 2019 (LCInitiative 2019). A Roadmap for developing the South African LCI Database was proposed in the outcomes of the REAL project (Notten and Von Blottnitz).

3.5.1. South African LCI datasets

With this international support, over 70 South African specific LCI datasets were developed in five data projects involving several South Africa universities and organizations: Blue North Sustainability, The Green House, University of Cape Town, the University of Johannesburg, and the University of the Witwatersrand, Johannesburg (Charikinya et al. 2018; Muigai and Pradhan 2018; Notten and Patel 2018; Russo and von Blottnitz 2018; Russo et al. 2018). Coverage of the data projects included (Figure 5):

- Major primary sectors of the South African economy – key agriculture products (maize, fruit, beef, wheat), key metals and minerals (coal, gold, platinum, ferrochrome, and heavy mineral sands), and electricity generation;
- Some manufacturing sectors – cement and concrete; synthetic fuels and chemicals; and
- Road and rail freight and domestic liquid fuels markets.

South African specific datasets on water supply and infrastructure, liquid fuels (petroleum refining), and solid waste disposal were also developed under the SRI program but that did not involve South African partners.

The new datasets are available in the ecoinvent database, through standard license agreements, with a subset of theses provided in the Global LCA Access Data (GLAD). Sectoral reports are available for the South African SRI LCI datasets, which describe the data collection and modeling of the datasets.

3.5.2. LCA capacity building in South Africa

The capacity building activities of the SRI program were delivered through a framework, with a consortium formed by the National Cleaner Production Centre of South Africa (NCPC-SA), the University of Cape Town (UCT), the Center for LCA Sustainable Design (CADIS), and Quantis. This consortium was also mandated to develop and organize “capacity building” events, with the purpose to increase the capacity for conducting LCA, and promote life-cycle thinking across the different sectors of the society in South Africa.

A baseline assessment carried out by UCT (Von Blottnitz and Russo 2018) provided insights into the knowledge gaps, and recommended to prioritize capacity building, and provide custom- made training for South Africa. A survey was done to determine the level of understanding of life-cycle thinking in the country. There were 51 respondents with a major presence from government departments (22%), followed by academia (20%), corporate (13%), consultants (12%), and others (33%). 80% of the respondents were familiar with the LCA framework. Respondents from academia, corporate, consultants, and self-employed (~57%) sectors generally possessed a satisfactory knowledge of LCA, and respondents from the government as well as industry associations (~26%) were shown have limited knowledge. Agriculture and related topics, followed by water treatment and management, specific products, and biofuels were the main subjects of their previous studies. The respondents highlighted the need for integration of life-cycle thinking into companies’ existing management and resource efficiency systems. Environmental LCA, with carbon- and water footprints, as well as life-cycle costing, emerged as the preferred topics for the training, with limited requests for EPDs.

Based on this feedback, training contents and practical exercises were developed using Story Telling and Participlan (Thomas 2014; New York University 2019). The training sessions were carried out in Durban and Pretoria (May 2018) with 29 and 53 participants, respectively. The profile of participants was mixed from industry, government, consultants, and academia. Participant’s knowledge ranged from a lack of previous LCA knowledge to intermediate knowledge.

4. Challenges, opportunities, and recommendations

Most research projects identified have been undertaken by several academic institutions and environmental consulting companies with few (available) studies emanating from private corporations, local and national government.

Although LCA, carbon- and water footprint studies have potential advantages for decision-making in business and policy, their implementation and impact remain limited. While the exact reasons are potentially different for their use in policy and business, specific challenges related to conducting LCAs in South Africa could include the accuracy and availability of data as well as the confidentiality of key parameters (Sevitz et al. 2003; Hoogevorst 2004; Buckley et al. 2011). Other aspects limiting the use of LCA are the scarcity of local expertise and the perceived high costs. Other limitations simply include the lack of will, policy drivers, or the understanding of how LCA could add value to existing systems. Some of these limitations are interlinked and solving one could remove other limitations as well. These may also be valid for the carbon- and water footprints; however, given that these types of studies are less data-intensive, results could be made available at a lower price. The impact of coal-based energy in South Africa should also be emphasized. There is a potential concern that LCA results could often lean towards a significant impact from coal emissions, overshadowing all other impacts. There is also a shortage of LCA studies in the tertiary sector, with more ‘product’ LCA studies available, suggesting an area for future growth.

The above-mentioned points have been partially overcome thanks to the SRI program, which were not limited to LCIs data collection but also aimed at building LCA/LCI expertise through dedicated training and workshops. The creation of regionalized LCIs represented a core purpose of the SRI program and these datasets now form a reliable pool of data for some South African sectors value chains which enhance the assessments of the environmental performance of local activities and products. This is an opportunity as they build a foundation that allows for the development of a South African national life cycle database as a repository of credible datasets useful in evidence-based policy- and decision-making advancing sustainable development. While the SRI program datasets are a long way off from being a complete database, the reliability of local South African LCA studies has been strengthened through their development. Even with a small number of datasets, the motivation and knowledge the project provided to the south African LCA community should allow for immediate incremental steps in advancing a database.

To enhance the accessibility and promote local data gathering, a first step is the need to establish a common data platform to consolidate available data in the country. A second step is the development of protocols to ensure and validate the quality of data in such an open-access database. The custodian of the database would need to be carefully considered to ensure the quality and continuity is maintained. This rigor will encourage a greater number of studies and might lead to wider uptake of LCA in the country, where in the past, costs of commercially available data sets were perceived as high for low returns.

Furthermore, with LCA being part of the draft Extended Producer Responsibility (EPR) regulations as a future legal requirements: "to conduct life cycle assessment in relation to product, in accordance with the relevant South African Bureau of Standards on International Organisation for Standardisation standards (ISO 14040 & ISO 14044)" in the Extended Producer Responsibility measure in the National Environmental Management: Waste Act, 2008 (Act no. 59 of 2008), there is growing pressure from Government to implement LCA at a broader scale in South Africa.

5. Conclusions

A total of 66 studies were located, including 27 LCA studies, 17 water- and 12 carbon footprinting studies as well as 10 EPDs. The number of local LCA-related research has increased in the past five years, which indicates a growing interest in life-cycle based thinking in South Africa. Academic institutions and environmental consulting companies have undertaken most studies. Few studies are publicly available from the private sectors. Many of the studies have been conducted for the agriculture and mining sectors, which are traditionally the major industries in South Africa. Future studies could include the packaging, energy, transport (road, rail, and air), and related industries which were not well represented.

The drivers for water footprint studies differed from LCAs as WF drivers were mainly connected to the Water Research Commission, and less to the private sector. This reflects the increased importance of water as a national strategic resource and more studies are encouraged to address gaps regarding water operations. More water footprints should be encouraged in sectors that have high water demand and have not been investigated before via a water footprint. These include municipalities, forest plantations, and various other water-intensive industry sectors. Geographically, seven of the water footprint studies were applied at a national level and nine at a regional or catchment level, with one at a municipal or local level. Considering that South African municipalities are large consumers, this is a research gap that needs further investigation and analysis.

While fewer carbon footprints are available in academic style literature, more companies are reporting carbon footprint results through carbon disclosure projects. In addition to the need for increasing the quantity of academic carbon footprint studies, the quality of the carbon footprints calculated by companies needs to be consistent. As a long-term goal, standardized carbon footprint methods (e.g. ISO or PAS) should be used as well as peer reviews for studies where results are published. There are also fewer environmental product declaration studies, but these are increasing.

The quality and quantity of environmental assessments improved in the last years through initiatives such as the SRI program, which is a noteworthy input in this regard. However, the outputs, e.g. datasets, of similar initiatives, particularly from international projects, could be placed in commercial paid-for LCA databases limiting their availability for local practitioners. Agreements for free-to-use or discounted access, especially for local providers of data, is one way to address this concern around those datasets. Once the core set of LCA datasets has been developed for the major industrial activities (mining, agriculture, energy), with more experience and background data LCA studies for other local markets and products (transport, services, and other industries) may follow more easily.

Overall, capacity-building activities in the country are still needed to further the implementation of life-cycle management practices in South Africa. While there are LCA studies and related methods in the country, the development of such in business and industrial spaces is perceived as a gap. Collaboration and communication between academia, business, governmental and non-profit organizations could lead to a stronger LCA community in general. It was also seen that a greater focus is needed in capacity building, to enable users to extract useful information from existing and future LCA studies.

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References

Agwa-Ejon JF, Pradhan A (2018) Life cycle impact assessment of artisanal sandstone mining on the environment and health of mine workers. Environ Impact Assess Rev 72:71–78. https://doi.org/10.1016/j.eiar.2018.05.005

Belgotex Floors (2016a) Structured Needle Punch Carpet Environmental Product Declaration. Global Green Tag BELCT001-B-2015

Belgotex Floors (2016b) SDX Tufted Bitumen Back Carpet Tile Environmental Product Declaration. Global Green Tag BELCT001-A-2015

Belgotex Floors (2016c) SDX Tufted Miraclebac Carpet Environmental Product Declaration. Global Green Tag BELCT001-C-2015

Bodunrin MO, Burman NW, Croft J, et al (2018) The availability of life-cycle assessment, water footprinting, and carbon footprinting studies in Brazil. Int J Life Cycle Assess 23:1701–1707. https://doi.org/10.1007/s11367-018-1484-2

Brent AC, Rohwer MB, Friedrich E, Von Blottnitz H (2002) Status of life cycle assessment and engineering research in South Africa. Int J Life Cycle Assess 7:167–172. https://doi.org/10.1007/BF02994051

Buckley C, Friedrich E, von Blottnitz H (2011) Life-cycle assessments in the South African water sector: a review and future challenges. Water SA 37:719–726

Burman NW, Croft J, Engelbrecht S, et al (2018) Review: life-cycle assessment, water footprinting, and carbon footprinting in Portugal. Int J Life Cycle Assess 23:1693–1700. https://doi.org/10.1007/s11367-018-1483-3

Charikinya E, Broadhurst J, Dlamini R, et al (2018) Primary production of precious and scarce metals: South Africa, In Metals. Zurich

Charles RG, Davies ML, Douglas P, et al (2019) Sustainable energy storage for solar home systems in rural Sub-Saharan Africa – A comparative examination of lifecycle aspects of battery technologies for circular economy, with emphasis on the South African context. Energy 166:1207–1215. https://doi.org/10.1016/J.ENERGY.2018.10.053

Chen H, Yang Y, Yang Y, et al (2014) A bibliometric investigation of life cycle assessment research in the web of science databases. Int J Life Cycle Assess 19:1674–1685. https://doi.org/10.1007/s11367-014-0777-3

Chevron Crushtech (2018a) Blue Core G6 Filling Environmental Product Declaration. Global Green Tag CHC-003-2018

Chevron Crushtech (2018b) Blue Core G5 Filling Environmental Product Declaration. Global Green Tag CHC-002-2018

Chevron Crushtech (2018c) Blue Core G7 Filling Environmental Product Declaration. Global Green Tag CHC-004-2018

Chevron Crushtech (2018d) Blue Core Building Sand Environmental Product Declaration. Global Green Tag CHC-001-2018

CIA Factbook (2020) South Africa — The World Factbook - Central Intelligence Agency. https://www.cia.gov/library/publications/the-world-factbook/geos/sf.html. Accessed 28 May 2020

CPD - Carbon Disclosure Project (2011) CDP South Africa JSE 100 Report 2011 - Partnering for a low carbon future

Croft J, Engelbrecht S, Ladenika AO, et al Review: the availability of life-cycle studies in Sweden

de Kock L, Russo V, von Blottnitz H (2019) Carbon intensive but decarbonising quickly? Retrospective and prospective Life Cycle Assessments of South African pome fruit. J Clean Prod 212:139–150. https://doi.org/10.1016/J.JCLEPRO.2018.12.026

Department of Environmental Affairs (2018) South Africa’s low emision development strategy. Pretoria

Deurer M, Green SR, Clothier BE, Mowat A (2011) Can product water footprints indicate the hydrological impact of primary production? - A case study of New Zealand kiwifruit. J Hydrol 408:246–256. https://doi.org/10.1016/j.jhydrol.2011.08.007

Devers L, Mathijs E, Kleynhans T (2012) Comparative life cycle assessment of Flemish and Western Cape pork production. Agrekon 51:105–128

Engelbrecht S, Ladenika AO, MacGregor OS, et al (2018) A discussion on the availability of life-cycle assessment studies in New Zealand. Int J Life Cycle Assess 23:1708–1713. https://doi.org/10.1007/s11367-018-1485-1

Estrela S (2015) I publish, therefore I am. Or am I? A reply to A bibliometric investigation of life cycle assessment research in the web of science databases by Chen et al. (2014) and Mapping the scientific research on life cycle assessment: a bibliometric analysis by Hou et al. (2015). Int J Life Cycle Assess 20:1601–1603. https://doi.org/10.1007/s11367-015-0951-2

Eustice T, van der Laan M, Van Antwerpen R (2011) Comparison of greenhouse gas emissions from trashed and burnt sugarcane cropping systems in South Africa. In: Proceedings of the Annual Congress-South African Sugar Technologists' Association. pp 326–339

Farzad S, Mandegari MA, Görgens JF (2017a) Integrated techno-economic and environmental analysis of butadiene production from biomass. Bioresour Technol 239:37–48

Farzad S, Mandegari MA, Guo M, et al (2017b) Multi-product biorefineries from lignocelluloses: a pathway to revitalisation of the sugar industry? Biotechnol Biofuels 10:87. https://doi.org/10.1186/s13068-017-0761-9

Fontes J (2015) Handbook for Product Social Impact Assessment: Roundtable for Product Social Metrics

Gobin A, Sparks D, Okedi J, et al (2019) Assessing the energy and carbon footprints of exploiting and treating brackish groundwater in Cape Town. Water SA 45:63–74

Goga T, Friedrich E, Buckley C (2019) Environmental Life Cycle Assessment for Potable Water Production – A Case Study of Seawater Desalination and Mine Water Reclamation in South Africa. Water SA 45:700–709

GreenCape (2019) Market Intelligence Report: Water. Cape Town

GreenDelta GmbH (2019) openLCA Nexus

Gyproc Saint Gobain (2018a) Rhinoboard 12.5 mm (Cape Town) Environmental Product Declaration. International EPD System S-P-01271-2018-02-28

Gyproc Saint Gobain (2018b) Rhinoboard 9.0 mm (Cape Town) Environmental Product Declaration. International EPD System S-P-01270-2018-02-28

Gyproc Saint Gobain (2019) Rhinoboard 9.0 mm (Brakpan) Environmental Product Declaration. International EPD System S-P-01568-2019-06-03

Haggard EL, Sheridan CM, Harding KG (2015) Quantification of water usage at a South African platinum processing plant. Water SA 41:279–286. https://doi.org/10.4314/wsa.v41i2.14

Harding G, Courtney C, Russo V (2017) When geography matters. A location-adjusted blue water footprint of commercial beef in South Africa. J Clean Prod 151:494–508. https://doi.org/10.1016/J.JCLEPRO.2017.03.076

Hoekstra AY, Chapagain AK, Aldaya MM, Mekonnen M (2011) The Water Footprint Assessment Manual: Setting the Global Standard. London

Hoogevorst A (2004) Integrated Environmental Management Information Series: Life Cycle Assessment

Hou Q, Mao G, Zhao L, et al (2015) Mapping the scientific research on life cycle assessment: a bibliometric analysis. Int J Life Cycle Assess 20:541–555. https://doi.org/10.1007/s11367-015-0846-2

International Organization of Standardization (ISO) (2006) ISO 14025:2016 Environmental labels and declarations — Type III environmental declarations — Principles and procedures. Switzerland

Janse van Vuuren P, Pineo C, Basson L (2015a) Regional Resource Flow Model: Fruit Sector

Janse van Vuuren P, Pineo C, Basson L (2015b) Regional Resource Flow Model: Wine Sector

JRC-IES (2011) ILCD handbook

Ladenika AO, Bodunrin MO, Burman NW, et al (2019) Assessing the availability of life cycle assessments in Austria. Int J Life Cycle Assess 24:614–619. https://doi.org/10.1007/s11367-018-1524-y

LCInitiative (2019) Development of National LCA Database Roadmaps – Life Cycle Initiative. https://www.lifecycleinitiative.org/development-of-national-lca-database-roadmaps/. Accessed 28 May 2020

Le Roux B, van der Laan M, Gush MB, Bristow KL (2018) Comparing the usefulness and applicability of different water footprint methodologies for sustainable water management in agriculture. Irrig Drain 67:790–799. https://doi.org/10.1002/ird.2285

le Roux B, van der Laan M, Vahrmeijer T, et al (2016) Estimating Water Footprints of Vegetable Crops: Influence of Growing Season, Solar Radiation Data and Functional Unit. Water 8:473. https://doi.org/10.3390/w8100473

le Roux B, van der Laan M, Vahrmeijer T, et al (2018) Water Footprints of Vegetable Crop Wastage along the Supply Chain in Gauteng, South Africa. Water 10:539

le Roux B, van der Laan M, Vahrmeijer T, et al (2017) Establishing and testing a catchment water footprint framework to inform sustainable irrigation water use for an aquifer under stress. Sci Total Environ 599–600:1119–1129. https://doi.org/10.1016/J.SCITOTENV.2017.04.170

Letete TCM, Mungwe NW, Guma M, Marquard A (2011) Carbon footprint of the University of Cape Town. J Energy South Africa 22:. https://doi.org/10.17159/2413-3051/2011/v22i2a3208

Mabiza MJ, Mbohwa C (2015a) Life Cycle Inventory Assessment of Smelting Process of Platinum Group Metals at the Anglo American Platinum Ltd, South Africa. In: The World Congress on Engineering. London

Mabiza MJ, Mbohwa C (2015b) Quantifying CO2-eq Emissions of Ore-based PGM Concentration Process in South Africa and Identification of Immediate Environmental Impacts, South Africa. In: The World Congress on Engineering 2015. London

Mabiza MJ, Mutingi C, Mbohwa M (2014) Life cycle inventory analysis and equivalent carbon dioxide emissions calculation of the mining and ore concentration processes of PGM at the anglo American Platinum Ltd, South Africa. In: 2014 IEEE International Conference on Industrial Engineering and Engineering Management. Selangor, pp 1018–1022

Maepa M, Bodunrin MO, Burman NW, et al (2017) Review: life cycle assessments in Nigeria, Ghana, and Ivory Coast. Int J Life Cycle Assess 22:1159–1164. https://doi.org/10.1007/s11367-017-1292-0

Mandegari MA, Farzad S, Görgens JF (2017a) Economic and environmental assessment of cellulosic ethanol production scenarios annexed to a typical sugar mill. Bioresour Technol 224:314–326

Mandegari MA, Farzad S, Rensburg E van, Görgens JF (2017b) Multi-criteria analysis of a biorefinery for co-production of lactic acid and ethanol from sugarcane lignocellulose. Biofuels, Bioprod Biorefining 11:971–990

Masindi V, Chatzisymeon E, Kortidis I, Foteinis S (2018) Assessing the sustainability of acid mine drainage (AMD) treatment in South Africa. Sci Total Environ 635:793–802. https://doi.org/10.1016/j.scitotenv.2018.04.108

Milà I Canals L, Chenoweth J, Chapagain A, et al (2009) Assessing freshwater use impacts in LCA: Part I - Inventory modelling and characterisation factors for the main impact pathways. Int J Life Cycle Assess 14:28–42. https://doi.org/10.1007/s11367-008-0030-z

Mohlotsane PM, Owusu-Sekyere E, Jordaan H, et al (2018) Water footprint accounting along the wheat-bread value chain: Implications for sustainable and productive water use benchmarks. Water (Switzerland) 10:1167. https://doi.org/10.3390/w10091167

Muigai R, Pradhan P (2018) Cement, concrete and related industries, South Africa, In Building materials. Zurich

Naicker V, Cohen B (2016) A life cycle assessment of e-books and printed books in South Africa. J Energy South Africa 27:68–77

National Planning Commission (2012) National Development Plan 2030: Our future - make it work. Pretoria

Ncongwane MS, Broadhurst JL, Petersen J (2018) Assessment of the potential carbon footprint of engineered processes for the mineral carbonation of PGM tailings. Int J Greenh Gas Control 77:70–81. https://doi.org/10.1016/J.IJGGC.2018.07.019

New York University (2019) Storytelling in Teaching and Learning

Nieder-Heitmann M, Haigh KF, Görgens JF (2019) Life cycle assessment and multi-criteria analysis of sugarcane biorefinery scenarios: Finding a sustainable solution for the South African sugar industry. J Clean Prod 239:118039. https://doi.org/10.1016/J.JCLEPRO.2019.118039

Notten P, Mason-Jones K (2012) Life cycle assessment of fresh milk and long life milk, with an emphasis on packaging, retail and distribution

Notten P, Mason-Jones K (2010) Life Cycle Assessment of Milk Production in the Western Cape

Notten P, Patel I (2018) Life Cycle Inventories of Coal mining and electricity production in South Africa. Zurich

Notten P, Patel I (2013a) Screening Life Cycle Assessment of Textiles Retailed in South Africa

Notten P, Patel I (2013b) Life Cycle Carbon Footprint of the North-South Corridor Road Network

Notten P, Patel I, Konz J (2015a) Life cycle Sustainability Assessment of Two South African Textile Value Chains: Cotton t-shirt and Cotton Towel: Technical Report

Notten P, Patel I, Logan A, Pieterse R (2015b) Life Cycle Assessment of South Africa and Namibian Beef Retailed in South Africa

Notten P, Von Blottnitz H Development of National LCA Database Roadmaps, including further Development of the Technical Helpdesk for National LCA Databases Deliverable D 4.3: final roadmap report for South Africa

Nyambo P, Wakindiki I (2015) Water footprint of growing vegetables in selected smallholder irrigation schemes in South Africa. Water SA 41:571–578. https://doi.org/10.4314/wsa.v41i4.17

Osman A, Crundwell F, Harding KG, Sheridan CM (2017) Application of the water footprinting method and water accounting framework to a base metal refining process. Water SA 43:722. https://doi.org/10.4314/wsa.v43i4.18

Owusu-Sekyere E, Jordaan H, Chouchane H (2017a) Evaluation of water footprint and economic water productivities of dairy products of South Africa. Ecol Indic 83:32–40. https://doi.org/10.1016/j.ecolind.2017.07.041

Owusu-Sekyere E, Scheepers ME, Jordaan H (2017b) Economic Water Productivities Along the Dairy Value Chain in South Africa: Implications for Sustainable and Economically Efficient Water-use Policies in the Dairy Industry. Ecol Econ 134:22–28. https://doi.org/10.1016/j.ecolecon.2016.12.020

Owusu-Sekyere E, Scheepers ME, Jordaan H (2016) Water footprint of milk produced and processed in South Africa: Implications for policy-makers and stakeholders along the dairy value chain. Water (Switzerland) 8:322. https://doi.org/10.3390/w8080322

Patel I, Notten P (2013) Life cycle assessment of sugar production in South Africa

Pegasys (2012) Water Footprint Analysis for the Breede Catchment, South Africa draft report. Cape Town

Pengelly C, Seyler H, Fordyce N, et al (2017) Managing Water as a Constraint to Development with Decision-Support Tools That Promote Integrated Planning: The Case of the Berg Water Management Area

Petersen AM, Knoetze JH, Görgens JF (2015) Comparison of Second-Generation Processes for the Conversion of Sugarcane Bagasse to Liquid Biofuels in Terms of Energy efficiency, Pinch Point Analysis and Life Cycle Analysis. Energy Convers Manag 91:292–301

Pfister S, Koehler A, Hellweg S (2009) Assessing the Environmental Impacts of Freshwater Consumption in LCA. Environ Sci Technol 43:4098–4104. https://doi.org/10.1021/es802423e

Pineo C, Janse van Vuuren P, Basson L (2015a) Regional Resource Flow Model: Grain Sector. Cape Town

Pineo C, Janse van Vuuren P, Basson L (2015b) Regional Resource Flow Model: Livestock and Game Sectors. Cape Town

Pryor SW, Smithers J, Lyne P, van Antwerpen R (2017) Impact of agricultural practices on energy use and greenhouse gas emissions for South African sugarcane production. J Clean Prod 141:137–145. https://doi.org/10.1016/J.JCLEPRO.2016.09.069

Ranchod N, Sheridan CM, Pint N, et al (2015) Assessing the blue-water footprint of an opencast platinum mine in South Africa. Water SA 41:287. https://doi.org/10.4314/wsa.v41i2.15

Ridoutt BG, Pfister S (2010) A revised approach to water footprinting to make transparent the impacts of consumption and production on global freshwater scarcity. Glob Environ Chang 20:113–120. https://doi.org/10.1016/j.gloenvcha.2009.08.003

Russo V, de Kock L, Muir K, et al (2018) Life Cycle Inventories of South African Agricultural Products, In Agriculture, forestry and animal husbandry. Zurich

Russo V, von Blottnitz H (2017) Potentialities of biogas installation in South African meat value chain for environmental impacts reduction. J Clean Prod 153:465–473

Russo V, von Blottnitz H (2018) Life Cycle Inventories of synthetic fuel production from coal and domestic fuel markets in South Africa. Zurich

Sango (2014) Case Study Report: Decision Making for Integrated Waste Management: Developing and Evaluating Waste Management Scenarios for Stellenbosch Municipality, 2014-2015

Scheepers ME, Jordaan H (2016) Assessing the blue and green water footprint of lucerne for milk production in South Africa. Sustainability 8:49

Sevitz J, Brent AC, Fourie AB (2003) An environmental comparison of plastic and paper consumer carrier bags in South Africa : implications for the local manufacturing industry. South African J Ind Eng 14:67–82

Siracusa V, Ingrao C, Lo Giudice A, et al (2014) Environmental assessment of a multilayer polymer bag for food packaging and preservation: An LCA approach. Food Res Int 62:151–161. https://doi.org/10.1016/j.foodres.2014.02.010

SRI (2020) About Sustainable Recycling Industries (SRI) – Sustainable Recycling Industries. https://www.sustainable-recycling.org/about-sri/. Accessed 13 Oct 2020

Statistics South Africa (2018) Mid-year population estimates 2018 (http://www.statssa.gov.za/publications/P0302/Media_Presentation.pdf). Pretoria

Statistics South Africa (2020) Gross domestic product: 4th quarter 2019 (http://www.statssa.gov.za/publications/P0441/GDP%202019%20Q4%20(Media%20presentation).pdf)

Steyn JM, Franke AC, van der Waals JE, Haverkort AJ (2016) Resource use efficiencies as indicators of ecological sustainability in potato production: A South African case study. F Crop Res 199:136–149. https://doi.org/10.1016/J.FCR.2016.09.020

The World Bank (2018) Overcoming poverty and inequality in South Africa - An assessment of drivers, constraints and opportunities. Washington

Thomas P (2014) Participlan - Group Facilitation

UNEP/SETAC (2009) Guidelines for social life cycle assessment of products

van der Laan M (2017) Application of water footprint accounting for selected fruit and vegetable crops in South Africa. Pretoria

van der Laan M, Jumman A, Perret SR (2015) Environmental benefits of improved water and nitrogen management in irrigated sugar cane: A combined crop modelling and life cycle assessment approach. Irrig Drain 64:241–252

Von Blottnitz H, Russo V (2018) Baseline study and LCA capacity building needs in South Africa. Cape Town

Vosloo P, Harris H, Holm D, et al (2016) Life Cycle Assessment of Clay Brick Walling in South Africa. The Clay Brick Association of South Africa: Technical Report 7A

Wettstein S, Muir K, Scharfy D, Stucki M (2017) The Environmental Mitigation Potential of Photovoltaic-Powered Irrigation in the Production of South African Maize. Sustainability 9:1772

Wiloso EI, Nazir N, Hanafi J, et al (2019) Life cycle assessment research and application in Indonesia. Int J Life Cycle Assess 24:386–396. https://doi.org/10.1007/s11367-018-1459-3

WorldAtlas (2017) The Economy Of South Africa. In: WorldAtlas. https://www.worldatlas.com/articles/the-economy-of-south-africa.html. Accessed 20 May 2020

Zanghelini GM, de Souza Junior HRA, Kulay L, et al (2016) A bibliometric overview of Brazilian LCA research. Int J Life Cycle Assess 21:1759–1775. https://doi.org/10.1007/s11367-016-1132-7

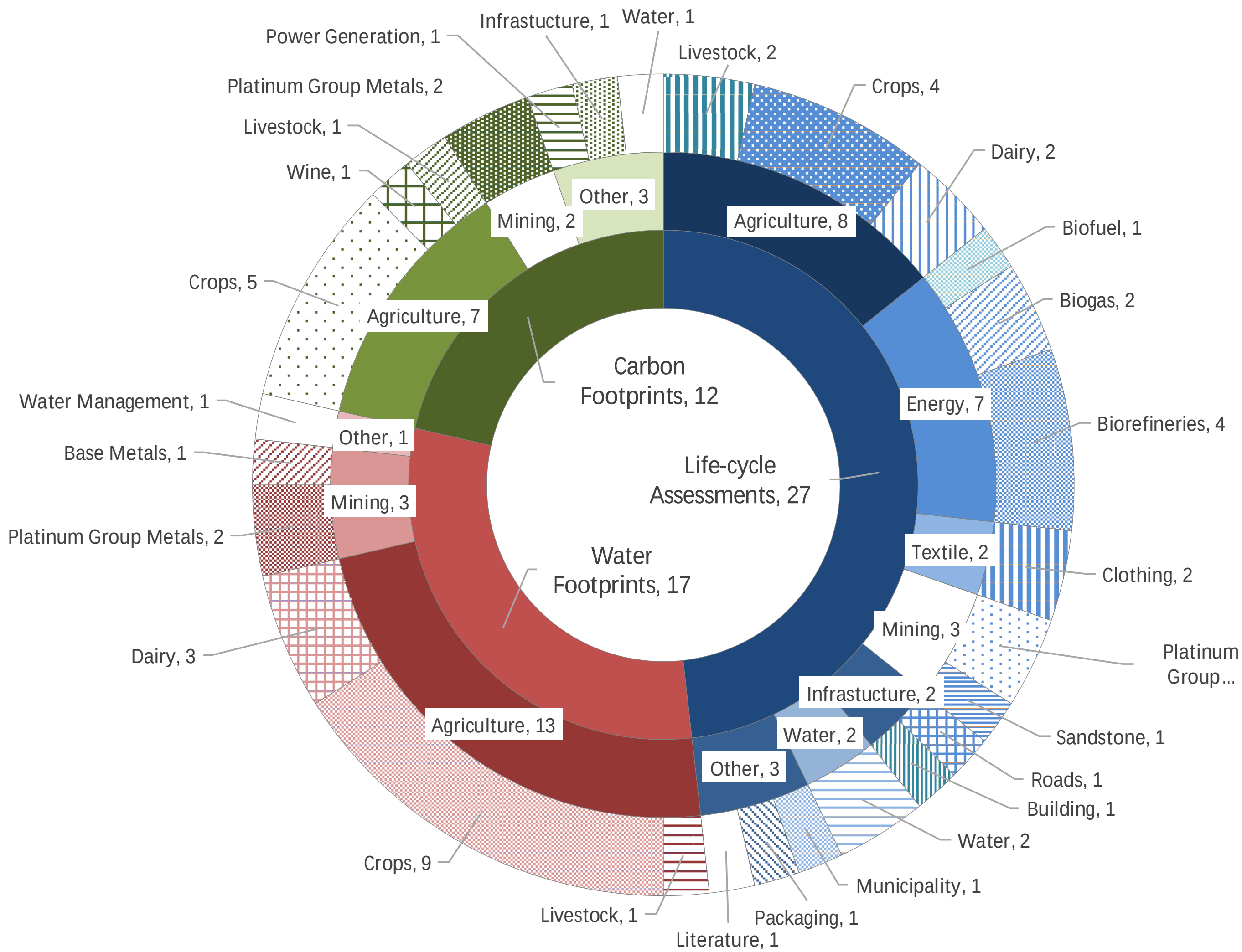

Figure 1: Summary of LCA-related environmental studies available in the literature for South Africa (2011-2019) (number of studies)

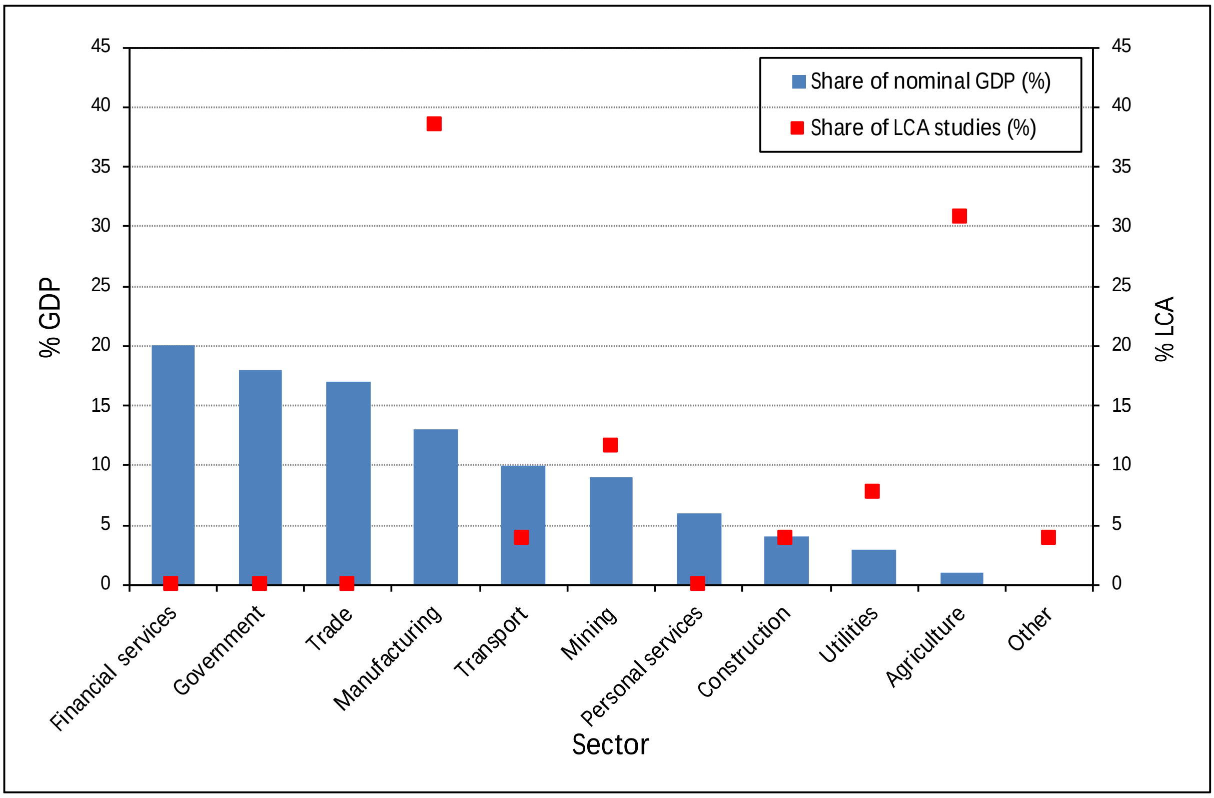

Figure 2: Relationship between the percentage share of nominal GDP (Q4, 2019) (Statistics South Africa 2020) and LCA studies in South Africa

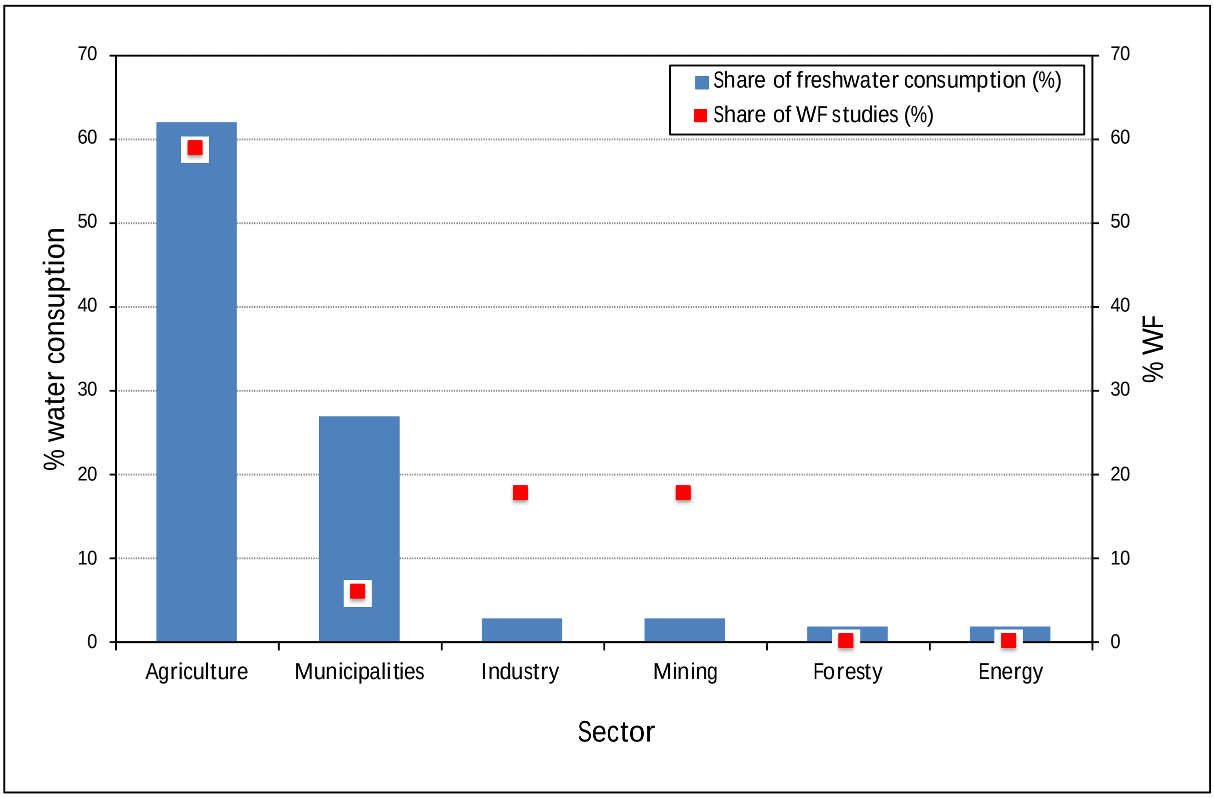

Figure 3: Relationship between the share of freshwater consumption (2019) (GreenCape 2019) and WF studies in South Africa

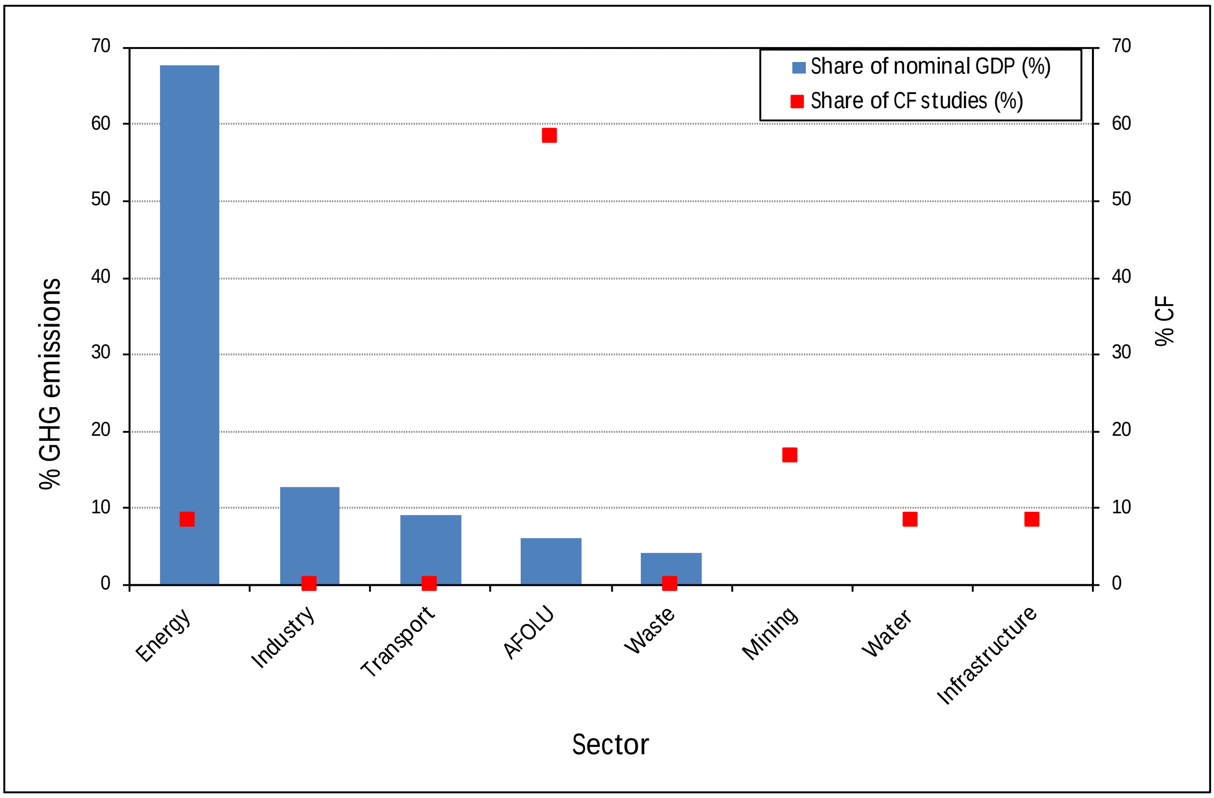

Figure 4: Relationship between the contribution to GHG emissions (2012) (Department of Environmental Affairs 2018) and CF studies in South Africa

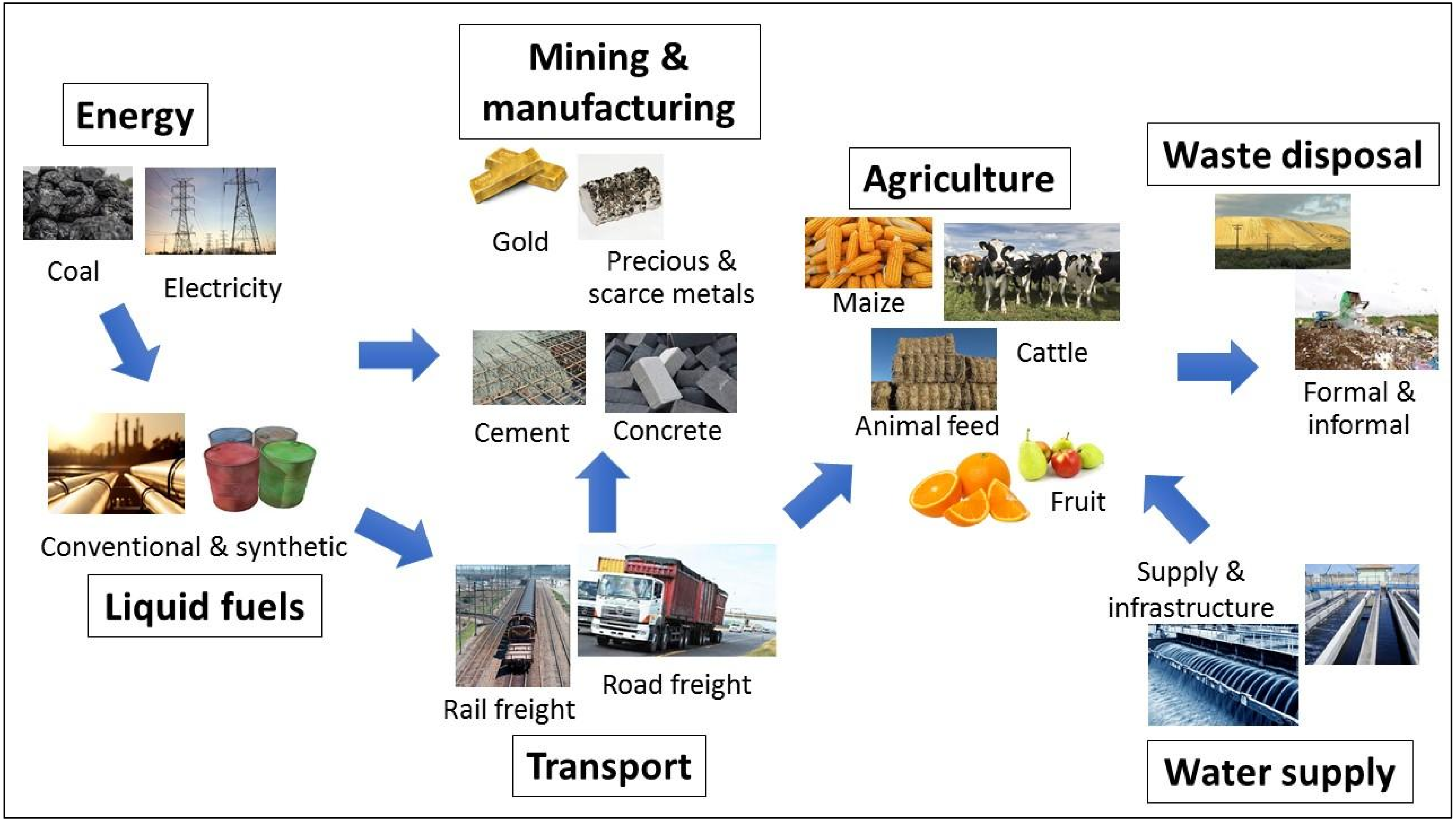

Figure 5: Building blocks to the start of a possible LCI database for South Africa

Table 1: Summary of available life-cycle assessment (LCA) studies in South Africa

	Sector	Project Title	Client*	Project Description	Location	Software	Impact Assessment Method/ Categories	Significant Findings	Reference
1	Agriculture	LCA of beef retailed in SA	WWF-SA/ Woolworths	Different beef production processes (free-range & feedlot) & the value chain incl. slaughtering, processing, packaging, distribution & retail	South Africa & Namibia	SimaPro	Regional methods for water stress, land use, acidification & eutrophication	Insight into beef production that will support Woolworths' promotion of farming practices	(Notten et al. 2015b)
2		LCA of Sugar	WWF-SA/ Sugar Association of SA (SASA)	Possible end uses of secondary products (molasses & bagasse), especially potential for renewable energy. generation	South Africa	SimaPro	ReCiPe 2008 & water footprint	The choice of optimal use of secondary products is not a simple one since it requires trade-offs between impacts.	(Patel and Notten 2013)
3		Comparative LCA of fresh milk & long-life (UHT) milk	Tetra Pak South Africa	Various milk products available on the SA market over the entire value chain: production, processing, packaging, distribution, retail, consumer use & packaging disposal	South Africa	SimaPro	ReCiPe 2008, focus on carbon footprint & (blue/ extractive) water footprint	Long-life milk has lower environmental impacts than chilled fresh milk across all impacts considered (largely due to lower returns/ losses & refrigeration savings at retail).	(Notten and Mason-Jones 2012)

4		LCA of fresh milk in the Western Cape of South Africa	WWF-SA/ Woolworths	Impacts of dairy production along a full supply chain. Functional unit: 1000 L of Fat & Protein Corrected Milk (FPCM) at the consumer	Western Cape	SimaPro	ReCiPe 2008 & CML 2001 method. Water & biodiversity indicators also developed.	For the carbon footprint, the farm stage is significant. Milk processing, retail & the consumer also accounted for significant impacts.	(Notten and Mason-Jones 2010)
5		Regional Resource Flow Model: Grain Sector Report	Western Cape Department of Economic Development and Tourism (DEDAT)	The goal was to demonstrate the complexity & variability within grain production & examine the feasibility & application of life-cycle based approaches for regional resource analyses	Representative farms in the West Coast district of the Western Cape	Umberto NXT Universal	ReCiPe (2008) method, valuation systems available in ecoinvent®, using midpoint metrics over a 100-year timeframe, with no normalization	1) There is a significant difference between irrigated & dry land wheat production; 2) The reduced impact of dry land production is due to water & electricity required for irrigation; 3) Eutrophication is similar across systems per hectare of planted wheat.	(Pineo et al. 2015a)
6		Comparative LCA of pork production	SAPPO (the South African Pork Producers Organisation)	Cradle-to-gate assessment to compare impacts of producing pork locally & exporting it to Flanders vs pork in Flanders & delivering it to the same location. Functional unit of	Western Cape in South Africa & Flanders in Belgium	GaBi	Global warming potential, eutrophication potential, acidification potential & energy use.	Flemish global warming potential, eutrophication potential, acidification potential & energy use were 56-, 65-, 62- & 59- respectively of Western Cape equivalents. The	(Devers et al. 2012)

				1 kg of Western Cape or Flemish pork (carcass weight) delivered to distribution centers in Antwerp.				exporting of pork accounts for less than 8% of environmental impacts in all impact categories.	
7		LCA of irrigated maize & potential emission reduction		To determine the environmental mitigation potential of replacing grid-powered irrigation in SA maize production with photovoltaic irrigation systems; including the value chain of maize production from cultivation to storage.	South Africa	SimaPro	Climate change, non-renewable energy, freshwater & marine eutrophication, land use, particulate matter, acidification, water footprint	Replacing grid electricity with photovoltaic-generated electricity leads to a 34% reduction in global warming potential of maize produced under irrigation & applied at a national level could potentially reduce SA greenhouse gas emissions by 536,000 t $CO_{2\text{-eq}}$ per year. Non-renewable energy demand, freshwater eutrophication & acidification are also significantly lowered.	(Wettstein et al. 2017)
8		LCA of irrigated sugarcane production	South African Sugarcane Research Institute	Mechanistic crop modeling combined with LCA to investigate the impacts of producing 1 tonne of	Pongola, South Africa	DSSAT-Canegro	Eco-Indicator 95, non-renewable energy consumption, global	Application of excess water & nitrogen to these systems has multiple impacts. The more judicious use of water & nitrogen	(van der Laan et al. 2015)

				extractable sucrose, with a focus on the impact of irrigation water & nitrogen fertilizer management.			warming potential, acidification (air) & eutrophication (water) potentials, water consumption	according to crop demands can lead to a 20% reduction in non-renewable energy consumption & 25% reduction in greenhouse gas emissions.	
9	Energy	LCA of sugarcane biorefinery scenarios	The Sugarcane Technology Enabling Programme for bioenergy (STEPBio) & the Sugar Milling Institute of South Africa (SMRI)	The sustainability of 6 biorefinery scenarios was assessed to identify potential problem areas & compare the impacts of the bio-products to one another, as well as to their fossil reference products.	South Africa	SimaPro	IPCC, GWP 100a	Sugarcane cultivation contributed most to the abiotic depletion, aquatic ecotoxicity, eutrophication & acidification impact categories which could be mitigated by increasing railway transport & applying effective fertilizer measures.	(Nieder-Heitmann et al. 2019)
10		LCA of biogas in the SA livestock industry		Investigating a biogas plant's potential to reduce emissions from poor waste management both at the feedlot & at the abattoir stage of the SA beef & pork value chain	South Africa	SimaPro	Global warming potential, eutrophication potential, acidification potential	Electricity generation from biogas & usage of co-produced heat would reduce GHG emissions by about 1.56 Mt CO_{2-eq} per year, reducing the carbon footprints of beef & pork by 10- & 30% respectively. Significant reductions of impacts	(Russo and von Blottnitz 2017)

								should be achievable by avoiding landfilling of wastes & over-fertilization of soils.	
11		LCA of alternative routes for converting sugarcane residues to biofuel		Detailed techno-economic evaluation & LCA were applied to model alternative routes for converting sugarcane residues (bagasse & trash) to selected biofuel and/or biochemicals in a biorefinery system.	South Africa	SimaPro	CML-IA baseline 3.02 & water scarcity	Modeling has demonstrated that biomass cultivation played an important role in the environmental burden, which demonstrated the importance of sustainable agricultural management on bio-based chemical production.	(Farzad et al. 2017b)
12		LCA of co-producing ethanol and electricity from sugarcane residues		Detailed economic & environmental analysis of different scenarios for co-production of ethanol & electricity was carried out & the results compared to the current case (where the bagasse is burnt in boilers of the sugar mill & trash is burnt on the field)	South Africa	SimaPro	CML-IA baseline 3.02	All investigated scenarios showed environmental benefit over the consumption of bagasse in the sugar mill, while the scenario with zero co-combustion of coal delivered the lowest environmental burden	(Mandegari et al. 2017a)

13		Sustainability assessment of lactic acid and ethanol co-production from sugarcane residue		4 potential biorefinery scenarios were developed to produce LA & EtOH as single products or co-produce LA from glucose and EtOH from xylose & vice versa. Simulations were developed using Aspen Plus software, & used for economic, energy & LCA evaluation.	South Africa	SimaPro	CML-IA baseline 3.02	The LA production scenario showed the most favorable economic performance, while the bioethanol-only production presented the minimum IRR, but the least contribution to environmental burdens across all impact categories.	(Mandegari et al. 2017b)
14		Economic and environmental analysis of butadiene production from sugarcane residue		Lignocellulose biorefineries annexed to a typical sugar mill were investigated to produce either ethanol or 1,3-butadiene (BD), utilizing bagasse & trash as feedstock.	South Africa	SimaPro	CML-IA baseline 3.02 & water scarcity	The economic evaluation indicated that bio-based BD production scenarios were not profitable. BD production from biomass had the potential to decrease GHG emissions by about 85% compared to current practice, whereas bio-energy self-sufficient scenarios delivered the best environmental performance across most categories.	(Farzad et al. 2017a)

15		Comparison of second-generation processes for the conversion of sugarcane bagasse to liquid biofuels		Energy efficiency study using process modeling, Process Environmental Assessments & LCA on 3 alternative liquid transportation biofuels produced from sugar cane bagasse.	South Africa	SimaPro	Global warming potential; acidification; abiotic depletion; eutrophication & human toxicity	Results indicate that advanced biological route increased efficiency & local environmental impacts while thermochemical routes have the highest efficiencies & low life cycle impacts.	(Petersen et al. 2015)
16	Textile	Life cycle sustainability assessment of 2 pilot textile value chains in Southern Africa	Southern African Sustainable Textile & Apparel Cluster (SASTAC)	To provide a baseline of the sustainability performance of the SA textiles industry & to pilot LCA against 2 cotton textile value chains – the cotton t-shirt & towel.	South Africa	SimaPro	Indicator set developed specifically for textiles in South Africa: Environmental indicators (JRC-IES 2011), social indicators (UNEP/SETAC 2009; Fontes 2015)	Demonstrated the usefulness of the LCA method in capturing the sustainability performance of value chains; provided insights into the socio-economic & environmental performance of textiles produced in SA.	(Notten et al. 2015a)
17		LCA of textiles retailed in South Africa	Woolworths	High-level LCA of a t-shirt retailed in SA focusing on the 2 main points of environmental leverage – the type of raw material used & the consumer use phase	Global production mix (representative of garment imports to SA); South African retail, distribution, use & disposal.	SimaPro	ReCiPe 2008 end-point categories & carbon footprint	Cotton production can have a negative impact in terms of water & chemical use. Polyester has a lower water impact, but recycled polyester was the	(Notten and Patel 2013a)

								most environmentally responsible choice.	
18	Mining	Mining & ore concentration of platinum group metals (PGMs)	Anglo American Platinum	Environmental impacts of PGM mining & ore concentration activities in South Africa. A functional unit of 1 tonne of ore mined was selected.	South Africa	Umberto	Emissions to air, water & soil in terms of global warming potential	Indirect emissions came mainly from the use of electric power produced from energy mix with 88% from coal-fired power generation. Conversely, direct emissions came from the direct consumption of non-renewable energy resources such as coal, petrol, diesel & LPG.	(Mabiza et al. 2014)
19		Smelting process of PGMs	Anglo American Platinum	Life cycle analysis of emissions from the smelter section of PGM recovery was developed & equivalent carbon dioxide emissions were quantified.	South Africa	Umberto	Emissions to air, water & soil in terms of global warming potential	For one metric ton of ore milled, a total of 2084.72 kg $CO_{2\text{-eq}}$ was associated with the smelting process. Notable airborne emissions were identified as sulfur dioxide efflux.	(Mabiza and Mbohwa 2015a)
20		LCIA of artisanal sandstone mining (ASAM)		Evaluation of the impact of ASAM on the environment & human health	QwaQwa, Free State	SimaPro	IPCC 2013 GWP 20a and IMPACT 2002+	Fossil fuel used during transportation was the highest contributor in most categories. High demand for physical labor also found to	(Agwa-Ejon and Pradhan 2018)

								have a detrimental effect on the health of miners.	
21	Infrastructure	LCA of the North-South Corridor Road network	TradeMark SA	The study included all phases in a road's life cycle including construction, maintenance, use & rehabilitation with the selected functional unit being the infrastructure & operation of the road network for 50 years.	Botswana, DRC, Malawi, Mozambique, Tanzania, Zambia, Zimbabwe, South Africa	SimaPro	CML 2001	The use of the road infrastructure is more significant in terms of a carbon footprint than construction & maintenance. The reduction of operational emissions should take priority.	(Notten and Patel 2013b)
22		LCA of clay brick walling	Clay Brick Association of South Africa	Cradle-to-gate, gate-to-end-of-operational-life & demolition, waste & recycle phases of the life cycle of clay bricks.	South Africa	SimaPro	Impact 2002+	Kilns that utilize a continuous firing process generally have lower impacts. There is also great potential to improve the environmental performance of the local clay brick manufacturing industry.	(Vosloo et al. 2016)
23	Water	Comparative LCA for the provision of potable water from alternative sources		Comparison of water treatment processes that use alternative sources of water such as	KwaZulu-Natal & Mpumalanga	SimaPro	ReCiPe	For the water sources investigated, the most significant stage was the operational stage; attributed to electricity use. Using	(Goga et al. 2019)

				seawater & mine-affected water.				solar & wind-generated electricity can reduce the impacts to levels comparable to the current purification of river water.	
24		Assessing the sustainability of acid mine drainage (AMD) treatment		The sustainability of acid mine drainage (AMD) treatment was examined where an integrated active process, *i.e*. magnesite, lime, soda ash & CO_2 treatment, was used.	Mpumalanga	SimaPro	IPCC 2013 and ReCiPe 2008	South Africa's fossil-fuel dependent energy mix & liquid CO_2 consumption were the major environmental areas of concern.	(Masindi et al. 2018)
25	Other	LCA & carbon footprinting for Western Cape Municipalities	Western Cape Government	Tailoring of EASETECH – a Danish LCA model – to the SA context, & use in determining the current impact of Stellenbosch Municipality's waste management system as well as the future impact of implementing alternative systems.	Stellenbosch Local Municipality	EASETECH model	IPCC 2007 - For this project, primarily focused on GWP	The biggest contributor to GWP occurs because of the high organic content of the municipal waste, & a predominantly landfill-based waste management system.	(Sango 2014)
26		LCA of a multilayer polymer bag		A screening LCA of a bi-layer film bag for food packaging	South Africa	SimaPro	Impact 2002+	The damage assessment showed that the most	(Siracusa et al. 2014)

				was carried out. Such packages are made of films obtained matching a layer of PA (Polyamide) with one of LDPE (Low-Density Polyethylene) with the functional unit chosen as 1 m^2 of plastic film delivered to the food production & packaging firm.				impacting phases are the production of the Polyamide (PA6) & Low-Density Polyethylene (LDPE) granules due to the consumption of primary resources, such as natural gas & crude oil.	
27		Comparative LCA of e-books & printed books		Environmental demands of reading printed books (print system) vs reading e-books from an Apple Air iPad (digital system), with a specific focus on the production of books & use of both options locally.	South Africa	SimaPro	ReCiPe & cumulative energy demand	Results demonstrate that the print system has lower impacts than the digital system in the impact categories of freshwater eutrophication, freshwater ecotoxicity, marine ecotoxicity & metal depletion, whilst the digital system has lower impacts in the remaining categories.	(Naicker and Cohen 2016)

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Table 2: Summary of available water footprint (WF) studies in South Africa

	Sector	Project Title	Client*	Project Description	Location	Method	Significant Findings	Reference
1	Agriculture	WF of commercial beef		To assess a range of stressed-adjusted blue/consumptive WFs for commercial beef in SA. A comprehensive top-down approach & a model of a generic herd was developed, by using elements of an LCA approach as a guide.	South Africa	WSI (Water Stress Index)	The base-case, unadjusted blue WF for beef is 437 L/kg carcass weight (CW); ranging between 105- & 2820 L_{eq}/kgCW. The best-feasible case result is a WF_{eq} of 276 L_{eq}/kgCW. The study highlighted the central interior of SA as an environmental hotspot.	(Harding et al. 2017)
2		Estimating WF of vegetable crops: Influence of growing season, solar radiation data & functional unit	Water Research Commission (WRC)	Assessing WFs of vegetable crops: carrots, cabbage, beetroot, broccoli & lettuce & grain crops maize & wheat. Unraveling the complexities of calculating these WFs.	Tarlton, South Africa	Hoekstra	Planting dates & inter-annual weather conditions & using different functional units affected WFs. Joining measures & estimated weather datasets affected model outcomes, which in turn impacted on WFs.	(le Roux et al. 2016)
3		Quantification of the WF of important fruit & vegetable crops produced in SA.	Water Research Commission (WRC)	WFs were undertaken using various approaches for significant fruit & veg crops growing in South Africa.	Gauteng & Western Cape	Hoekstra, LCA, hydrological-based	WFs were estimated for key fruit & vegetable crops grown in SA. WFs were also estimated using crop nutritional value as the functional unit. Upscaling exercises were conducted for the Steenkoppies Aquifer & Olifants-Doorn Water Management Area.	(van der Laan 2017)

4		WF of Vegetable Crop Wastage along the Supply Chain in Gauteng, South Africa	Water Research Commission (WRC)	Water footprints were calculated for wastage of carrots, cabbage, beetroot, broccoli & lettuce produced on the Steenkoppies Aquifer along the supply chain.	Tarlton, South Africa	Hoekstra	The highest percentage of wastage occurs at the packhouse level, some crops have higher wastage than others; lettuce (38%) compared to cabbage (14%). Wastage varied between seasons. Blue water lost on the aquifer due to vegetable crop wastage (4 mm^3 / year) represented 25% of estimated blue water volume that exceeded sustainable limits (17 mm^3/year).	(le Roux et al. 2018)
5		Comparisons of different WF methodologies for application in agriculture in SA	Water Research Commission (WRC)	Based on a case study centered around apple production in SA, 3 common WF methodologies were evaluated.	No specific location.	Hoekstra, LCA, hydrological-based	The WFN approach was judged to be most useful to water resource managers in SA due to its quantitative approach, while the LCA approach appears best for the comparison of different products. No single WF metric can be used to inform wise consumer decisions due to the complexity involved.	(Le Roux et al. 2018)
6		A WF framework to assess the sustainability of blue water use for	Water Research Commission (WRC)	Part of a 4-year study to explore the use of water footprint accounting in SA	Steenkoppies Aquifer, Gauteng	Hoekstra	A catchment-scale water balance was estimated using WF accounting. Results indicated that	(le Roux et al. 2017)

		an aquifer under stress		irrigated fruit & vegetable production.			irrigation on the aquifer is currently unsustainable. It was proposed that the simple framework developed can be used for real-time water resources management.	
7		Assessing the blue & green WF of lucerne for milk production in SA		WFs were calculated for lucerne (*Medicago sativa*) that serves as livestock feed for milk production.	Vaalharts irrigation scheme, Northern Cape, South Africa	Hoekstra	The WF of milk production is environmentally sustainable & highlighted the importance of reporting WFs with a sustainability assessment.	(Scheepers and Jordaan 2016)
8		WF of growing vegetables in selected smallholder irrigation schemes in South Africa.		WFs were calculated for the cultivation of various crops, including cabbage, tomatoes, spinach, potatoes & green beans cultivated under different smallholder irrigation schemes.	Eastern Cape, KwaZulu Natal & Limpopo Provinces, South Africa	Hoekstra	WFs varied between irrigation systems & over time. Variations are due to different weather conditions, planting season & field management practices.	(Nyambo and Wakindiki 2015)
9		WF analysis for the Breede Catchment, South Africa draft report, Breede Overberg Catchment Management Agency		Water footprints were calculated for agriculture in the Breede Water Management Area & were considered to assess water used in terms of economic gains & job creation.	Breede Catchment, South Africa	Hoekstra	WFs provided important information for water allocation decisions, e.g. apples produced in Overberg West created more jobs than those produced in the Central Breede per volume of water; apples & tables grapes created more jobs & income than wine grapes per volume of	(Pegasys 2012)

							water; & cereals & fodder used water inefficiently.	
10		WF accounting along the wheat-bread value chain: Implications for sustainable & productive water use benchmarks		Water footprint & economic water productivities of the wheat-bread value chain were assessed.	Bainsvlei & Clovelly in South Africa	Hoekstra	The average WF for wheat bread was 954.53- in Bainsvlei & 1026.53 m^3 per ton in Clovelly. More than 99% of the water was used for wheat production. Approx. 80% of the WF over the entire value chain was blue water.	(Mohlotsane et al. 2018)
11		Economic water productivities along the dairy value chain in South Africa: Implications for sustainable & economically efficient water-use policies in the dairy industry		Economic water productivities along the dairy value chain in South Africa were assessed.	South Africa	Hoekstra	Milk production in South Africa is economically efficient in terms of water use. Future ecological footprint assessments should consider the value-added to output products & economic water productivities, rather than relying only on water footprint estimates.	(Owusu-Sekyere et al. 2017b)
12		WF of milk produced & processed in SA: Implications for policymakers & stakeholders along the dairy value chain		Assessing the WF of producing & processing milk in South Africa.	South Africa	Hoekstra	Corn, sorghum & lucerne production under irrigation in the greater Orange River basin is sustainable, whereas oats production for silage in the same catchment area is not sustainable.	(Owusu-Sekyere et al. 2016)
13		Evaluation of WF & economic water productivities of		Assessment of water footprints & economic water productivities of dairy	South Africa	Hoekstra	WFs of South Africa’s dairy products are higher than the global averages.	(Owusu-Sekyere et al. 2017a)

		dairy products of SA		products in SA for the periods 1996–2005 & 2006–2013.			Dairy production under a mixed system is economically productive in terms of water use. Green water contributes the highest to the total water footprint.	
14	Mining	Assessing the blue-water footprint of an opencast platinum mine in South Africa		Mineral extraction at this site occurs by conventional opencast methods. Functional unit is taken as the volume of water consumed to produce 1 tonne of refined platinum (m^3/t).	Northern region of SA	Hoekstra (Blue only)	The largest consumption of water was due to evaporation from the mineral processing operations (36.8%) & the tailings storage facility (19.4%).	(Ranchod et al. 2015)
15		Quantification of water usage at a South African platinum processing plant		The direct water footprint for 2 concentrators, a smelter & a tailings dam of a platinum processing plant were calculated. This included the sum of the blue-, green- & grey-water footprints.	Northern region of SA	Hoekstra	The water footprint calculated from June 2012 until May 2013 was 201 m^3/kg PGM (platinum group metals). Overall, the total grey-water footprint made the largest contribution, accounting for 73%, the blue-water footprint was the 2nd largest (27%), & there was no green-water footprint.	(Haggard et al. 2015)
16		Water accountability & efficiency at a base metal refinery		Survey of the potable & stormwater systems at a base metal refinery to assess the water accountability & determine means for improvement.	Northern region of SA	Hoekstra	The blue & green water footprint was calculated to be 33.4- and 10.5 m^3/t & respectively. The total water footprint of the refining process was 43.9	(Osman et al. 2017)

							m^3 of water per tonne of base metal produced.	
17	Other	Managing water as a constraint to development with decision-support tools that promote integrated planning: The case of the Berg Water Management Area	Water Research Commission (WRC) & Western Cape Provincial Government	This study aimed to better integrate water into economic development planning through the development of decision-support tools.	Berg Water Management Area, Western Cape		Under all climate change models, irrigated agriculture required more water to remain sustainable. When water is analyzed as a constraint to the local economy, the West Coast municipalities of Swartland, Saldanha Bay & Bergrivier emerge as areas where water is likely to be a significant future constraint.	(Pengelly et al. 2017)

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Table 3: Summary of available carbon footprint (CF) studies in South Africa

	Sector	Project Title	Client*	Project Description	Location	Significant Findings	Reference
1	Agriculture	Regional Resource Flow Model: Fruit Sector Report	Western Cape Department of Economic Development & Tourism (DEDAT)	Analysis of the carbon footprint of Western Cape fruit using Confronting Climate Change carbon footprint data.	Western Cape	Softer fruits, which require more packaging, have higher carbon footprints than harder fruits. This provides incentives for the industry to switch to renewable energy sources & alternative packaging materials.	(Janse van Vuuren et al. 2015a)
2		Regional Resource Flow Model: Wine Sector Report	Western Cape Department of Economic Development & Tourism (DEDAT)	Analysis of the CF of Western Cape wine using Confronting Climate Change carbon footprint data. This was compared to global industry benchmarks.	Western Cape	South African wine production seems to have a larger carbon footprint than its international competitors, primarily because of electricity use & packaging.	(Janse van Vuuren et al. 2015b)
3		Regional Resource Flow Model: Livestock & Game Sector Report	Western Cape Department of Economic Development & Tourism (DEDAT)	GHG emission estimates were developed for livestock, dairy & game.	Western Cape specifically & South Africa	The Western Cape profile for GHG contributions from animal production differs from that for South Africa, highlighting different focus areas for national & provincial strategies.	(Pineo et al. 2015b)
4		Comparison of greenhouse gas emissions from trashed & burnt sugarcane cropping systems in South Africa	South African Sugarcane Research Institute	Modeling study to investigate the comparative GHG emissions from burnt versus trashed sugarcane cropping systems under rainfed production.	Mount Edgecombe, KwaZulu-Natal, South Africa	Counter-intuitively, sugarcane cropping systems that were trashed before harvest had a higher CF than systems for which the leaves were burnt. In the trashed system, the sequestration of carbon in soil was only possible up to a certain threshold. The capacity to estimate site-specific emissions mechanistically is limited & requires further work.	(Eustice et al. 2011)

5		Impact of agricultural practices on energy use & greenhouse gas emissions for SA sugarcane production		An LCA approach was used to model primary fossil fuel energy inputs & GHG emissions associated with the production of sugarcane in two distinct regions, the irrigated North & the non-irrigated North Coast.	North Coast, South Africa	Despite higher energy inputs in the irrigated North, GHG emissions are similar for sugarcane produced in each region. Green cane harvesting reduces energy inputs & emissions by 4- & 16%, respectively, in both regions.	(Pryor et al. 2017)
6		Prospective LCA of South African pome fruit		The global warming potential of South African apples & pears (pome fruit) for the years 2000, 2010 & 2020 was determined & compared to that cultivated & packaged in other countries.	South Africa	Results indicated a decrease in the aggregated GWP of pome fruit from 1.52- in 2000 to 1.23- in 2010 and finally 1.02 kg $CO_{2\ eq}$/kg fruit in 2020. The life cycle stage with the largest contribution was the Controlled Atmosphere store.	(de Kock et al. 2019)
7		Resource use efficiencies as indicators of ecological sustainability in potato production		Assessment and benchmarking of production regions, representing different growing conditions, regarding their use of input resources & to identify resource-intensive practices	South Africa	Fertilizers (34%) & irrigation (30%) were the greatest contributors to energy use. The energy required to pump water was strongly related to the amount of irrigation applied, pumping depth, and distance.	(Steyn et al. 2016)
8	Mining	Quantifying $CO_{2\text{-}eq}$ emissions of Ore-based PGM concentration process in SA & identification of immediate environmental impacts	Anglo Platinum Limited	Life cycle analysis of ore-concentration was developed & equivalent carbon dioxide emissions quantified.	Northern region of SA	For one metric ton of PGM concentrate, 1.57 kg $CO_{2\text{-}eq}$ was associated with this process. Important emissions were waterborne & emissions to the soil.	(Mabiza and Mbohwa 2015b)

9		Assessment of the potential CF of engineered processes for the mineral carbonation of PGM tailings		Evaluated the viability of using PGM tailings for carbon sequestration through mineral carbonation based on CF.	South Africa	Selected processes are carbon positive *i.e.* ineffective as net carbon sinks. The operations contributing the most to the overall emissions are heating and chemical reagent make-up.	(Ncongwane et al. 2018)
10	Power Generation	A comparative examination of life-cycle aspects of battery technologies for a circular economy		GWP was assessed to produce batteries for several systems.	Durban, South Africa	CF of battery production is useful for a comparative analysis of GWP but gives only a limited picture of the environmental impacts of batteries.	(Charles et al. 2019)
11	Infrastructure	CF of the University of Cape Town (UCT)		Determine the CF of UCT for 2007.	Cape Town	CF was found to be about 83 400 tons CO_2-eq, with energy consumption, transportation & goods & services contributing about 81-, 18- & 1% respectively.	(Letete et al. 2011)
12	Water	CF of exploiting & treating brackish groundwater		Explored the links between energy usage in the water sector & its CF with 3 scenarios investigated - 'centralized', 'desalination' & 'decentralized'.	Cape Town	The centralized approach's energy intensity was found to be the lowest of the three (1.16-1.57 MJ/m^3), while those of the decentralized & desalination approaches ranged from 3.57- to 7.31 MJ/m^3 & 7.41- to 9.62 MJ/m^3 respectively.	(Gobin et al. 2019)

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