MANAGEMENT OF IMPORTED SUPPLY CHAIN PRODUCTS: INCORPORATING COUNTRY-SPECIFIC SUSTAINABILITY CRITERIA IN LIFE CYCLE DECISION ANALYSIS

Alan C Brent

Chair: Life Cycle Engineering
Department of Engineering and Technology Management
University of Pretoria, South Africa

Abstract: Sustainability criteria for life cycle management in the South African context differ from other regions of the world. From an environmental perspective, natural water resources are limited and significant losses of topsoil have been experienced, which is seen as an important agricultural resource. Water and land should therefore be considered as specific criteria where certain materials or components in the automotive life cycle rely heavily on these resources, e.g. leather and natural fibres for interior finishing. Also, waste management was not given a high priority historically, which has resulted in the lack of long term planning, information, legislation and the capacity to handle waste streams. Similar to the use of water and land, waste streams that influence the ambient quality of air, water and land resources are important factors in the life cycle management of materials and products imported from South Africa. Furthermore, from an economic perspective, mined resources are important and the impact on current reserves must also be considered together with the other environmental resources. Two examples are given of automotive components exported by the manufacturing sector in South Africa and their related impacts.

1. INTRODUCTION

1.1. The South African automotive sector

The 1990s have seen a turn in the South African manufacturing sector. With a decline in the economic importance of the primary manufacturing sector the contribution of the secondary industries have increased [1]. Prior to the 1990s the manufacturing sector was dominated by heavy industries relating to petroleum, chemical and metallurgical products. Government subsidies strongly supported these industries during the economic sanctions in the latter half of the 1980s and especially with respect to energy supply. South Africa has significant coal reserves, and the electricity generation and manufacturing greatly rely on this mined resource [1], primarily through government infrastructure projects. Approximately 90% of the electricity supply in South Africa is based on coal-fired technology [2]. Additionally, one-third of the country's liquid fuel and most of the petrochemical products are produced from coal [3] and South Africa consequently ranks amongst the 20 largest carbon dioxide emitting countries [4]. The manufacturing sector as a whole contributes 27% to the South African Gross Domestic Product (GDP), of which less than 4% is attributable to the chemicals manufacturing industry [5]. Although heavy metallurgical industries are still essential to the South African economy, the export of value-added products from these minerals has increased significantly since the 1994 democratic elections [6]. The observed increase in the exports is partially attributable to the South African automotive industry, which has seen the introduction of the Motor Industry Development Programme by the national Department of Trade and Industry [7]. Since the start of the initiative in 1995, a 37% increase in the average annual export rate was achieved, with export of passenger vehicles increasing by approximately 185% since 1998 [1]. The growth in the production rate of Original Equipment Manufacturers (OEMs) has subsequently resulted in the expansion of the South African supply chain as well. Table 1 summarises the most important sectors and export markets of the South African automotive industry.

Table 1: Priority South African automotive sectors and export markets

Priority sector	Priority export market	Destination of total exports
Light commercial vehicles	European Union Southern African Development Community Australia Japan United States of America	52.8 % 11.9 % 12.0 % 11.0 % 7.3 %
Medium and heavy commercial vehicles	Southern African Development Community European Union United States of America	55.9 % 28.2 % 14.7 %
Automotive components: • Catalytic converters • Stitched leather components • Automobile tyres • Road alloy wheels and parts • Engine parts • Silencers and exhausts • Automotive tooling • Wiring harnesses • Automobile glass • Ignition and starting equipment	European Union United States of America Southern African Development Community	69.8 % 9.5 % 5.6 %

1.2. Environmental pressures of the South African automotive manufacturing supply chain

The South African automotive manufacturing supply chain contributes to the national environmental concerns, primarily through [8]:

- Over-abstraction from surface and ground water resources.
- Salinisation of surface water due to the discharge of saline effluent from manufacturing and processing industries, irrigation, the discharge of underground water pumped from mines (which also leads to acid mine drainage), and the discharge of treated sewerage effluents.
- Destruction of riparian and in-stream habitat.
- Discharge of toxic substances at point and diffuse sources.
- Health and environmental impacts on groundwater resources due to diffuse pollution.
- Production of solid waste.
- Emissions of greenhouse gases and other air pollutants.
- Loss of biodiversity and valuable land, for example the degradation of wetlands in mining areas, invasion of riparian zones by invasive plants due to bad management practices, etc.
- Localised pollution through spillages and accidental leakages that may cause health problems and damage to ecosystems in the immediate vicinity.

The manufacturing sector of South Africa is further resource intensive in terms of mineral and fossil fuel usage [9]. The environmental impacts associated with the industry sector of South Africa can therefore be grouped into the four main categories of air, water, land and mined resources, as is shown in Figure 1 [10]. Environmental pressures with respect to air and mined resources are similar to other parts of the world. However, impacts on water and land resources differ to some extent, not only from regions external to South Africa, but also within the national borders.

1.2.1. Water resources in the South African context

Water as a resource is extensively addressed in the South African national State of the Environment report [11]. South Africa is a semi-arid country with an average rainfall of 500 mm per year and lacks important arterial rivers or lakes with extensive water conservation and control measures essential as the growth in water usage threatens the available supply [12]. Ambient natural surface and ground water is recognised as a limiting factor to growth [13], and the management of these resources is therefore imperative. The main stresses include:

- Damming of all the major rivers.
- Surface and groundwater pollution from effluents.
- More than 50% conversion of wetlands in some areas, with changes in habitat affecting the biotic diversity of freshwater ecosystems.

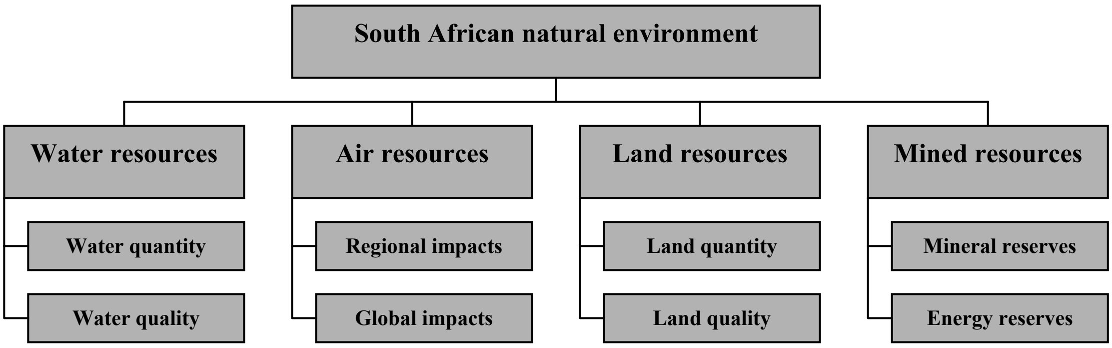

Figure 1: Framework to classify the environmental impacts of the South African manufacturing industry

1.2.2. Land resources in the South African context

The maintenance of the biodiversity of the terrestrial resources is seen as a prerequisite for ecosystem sustainability in South Africa [11]. South Africa is ranked as the third most biologically diverse country in the world and is characterized by a wide diversity of plant and animal life, including [14]:

- Over 18 000 species of vascular plants, of which over 80% occur nowhere else.
- 5.8% of the world's mammal species.
- 8% of the world's bird species.
- 4.6% of the world's reptile species.
- 16% of marine fish species.
- 5.5% of the world's recorded insect species.
- 15% of the world's total coastal species, with approximately 12% of these occurring nowhere else.

The biodiversity is caused by a variation in climate, geology, soils and landscape forms [11] with sporadic wet and dry periods. These variations also imply fragile terrestrial systems, e.g. 91 % of the country falls within “affected dry lands” as defined by the United Nations [15]. Land mismanagement due to the removal of ground cover vegetation in some of these dry lands have resulted in the dramatic increase in the loss of topsoil (35 %) [16]. The resulting fewer fertile soils is less able to support vegetation (natural or cultivated crops) in the future. Of the total surface area, 86% is classified as agricultural, although most of this is grazing land, rather than crop cultivation and South Africa consequently also has the highest concentration of threatened natural plant groups in the world [17, 18]. South Africa currently formally conserves only 6% of the whole country and several vegetation types are under-represented, as opposed to the 10 % stipulated by the United Nations Conference for Environment and Development in Rio de Janeiro in 1992 [19, 20, 21]. Furthermore, a land ownership reform process has taken place since 1994, allowing all South Africans fair access to land and natural resources [11]. This has resulted in more than 6 million hectares of previously state-owned land now being more intensively cultivated [22].

When evaluating the specific impacts associated with the supply chain of the South African automotive sector, special attention must therefore be given to water- and land-use and transformation, minimizing the effects of loss of habitat and of prime agricultural land, as well as water and land pollution and degradation in its broadest sense. In order to improve the accuracy of an industrial activity evaluation, regions must be identified within the national borders that are characteristic of the diversity found with the South African natural environment.

2. SOUTH AFRICAN LIFE CYCLE REGIONS

The different climate, geology, soils and landscape forms are captured in eco-regions that have been defined across the globe [23]. South Africa includes 18 of these eco-regions, which are described in terms of information extracted from morphological [24] and vegetation information [21], and therefore represent the 68 vegetation types found in South Africa. The eco-regions are also closely associated with the high variability of the hydrological regime of the country [25]. The relationship of the defined eco-regions and the surface runoff of South Africa can be seen by comparing Figures 2 and 3 [25]. Furthermore, the South African freshwater surface runoff have been defined in terms of 22 primary water catchments, which represent specific river basins, etc. Eco-regions and vegetation types do occur in multiple primary catchments. However, by grouping the primary catchments, South Africa can be subdivided into larger regions that maximise the inclusion of the eco-regions and vegetation types and thereby improve the regional-specific impacts associated with the manufacturing industry. The grouped regions, termed South African Life Cycle (SALCA) Regions, whereby an improved assessment of the life cycle impacts of the automotive supply chain can be performed, are shown in Figure 4 [25].

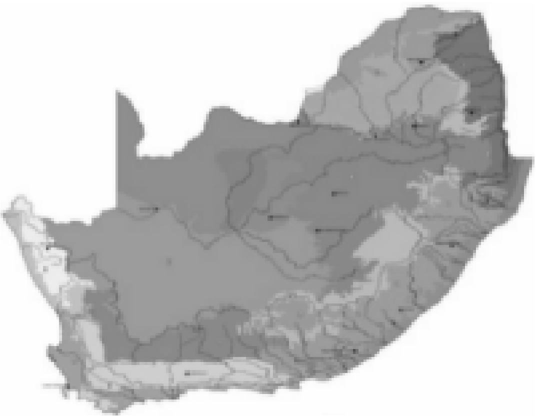

Figure 2: Eco-regions of South Africa

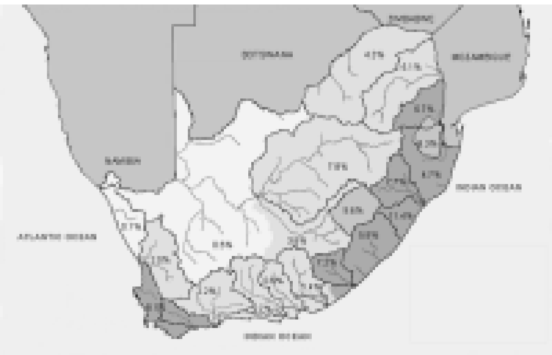

Figure 3: Surface runoff of South Africa

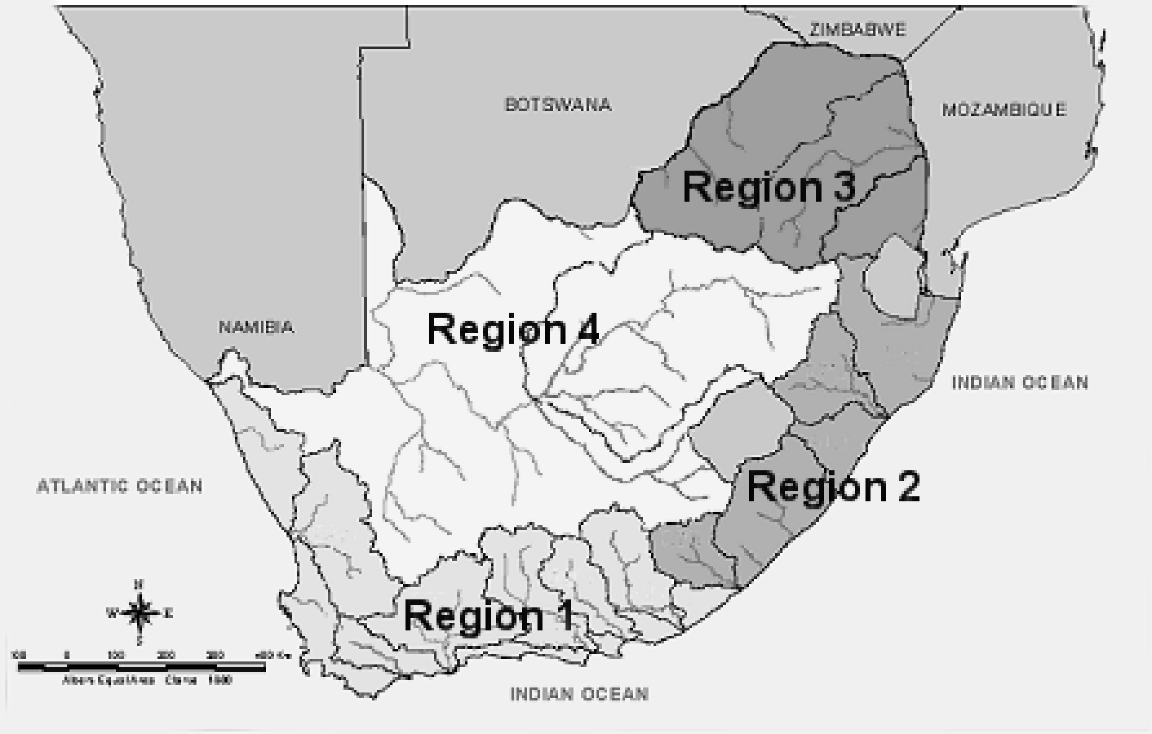

Figure 4: South African Life Cycle Assessment (SALCA) Regions grouped from water catchments

Table 2: Representation of the eco-regions and vegetation types in the SALCA Regions

South African eco-regions (total of 18)			**South African vegetation types (total of 68)**		
Percentage inclusion of an eco-region in a SALCA Region	**Number of eco-regions represented**	**Cumulative percentage of total eco-regions**	**Percentage inclusion of a vegetation type in a SALCA Region**	**Number of vegetation types represented**	**Cumulative percentage of total vegetation types**
100 %	7	39	100 %	37	54
> 90 %	12	67	> 90 %	49	72
> 80 %	14	78	> 80 %	54	79
> 70 %	16	89	> 70 %	60	88

Table 2 indicates that more than two-thirds of the surface areas are included in the SALCA Regions for approximately 90 % of the South African eco-regions and vegetation types. Less than 6 % of the eco-regions and vegetation types are not represented adequately, i.e. less than 60 % of the respective surface areas fall within the defined SALCA Regions. This amounts to 1 eco-region and 3 vegetation types, which are too widespread across the country.

The SALCA Regions more accurately signify the region-specific water and land impacts associated with the South African manufacturing sector, without being too site-specific as is required by, for example, an Environmental Impact Assessment (EIA).

3. CASE STUDY 1: METAL COMPONENT

In order to demonstrate the implications of a region-specific approach, two case studies in the automotive supply chain will be used. The first evaluates the typical life cycle of lightweight (aluminium) brake callipers, manufactured and assembled in South Africa for export purposes to Europe. The stages in the life cycle of such a South African brake calliper, and the associated SALCA Regions, are shown in Figure 5 [26]. Transport processes are not included in the figure as these could be region-specific or cross regional, e.g. bauxite is transported by sea from Australia, etc. to the east coast of South Africa, while road transportation is used for long distance haulage of materials and components within the borders of South Africa. Table 3 indicates the primary environmental concerns at each of the South African life cycle stages. With reference to Figure 1, the brake calliper system has impacts associated with the South African water, air, land and mined resources.

3.1. Water resources impact

Water usage, i.e. quantity, and water quality impacts are mainly attributable to the aluminium ingot production, primarily aqueous fluorides [27], and the generation of electricity. In terms of the latter, the majority (13.8 MWh/tonne) is used during the manufacturing of the aluminium alloy (including ingots) from bauxite and other minerals [26]. Coal-fired electricity, in turn, is primarily generated in SALCA Region 3 [2] in areas where water resources are already under stress [13] and effluents and water usage are highly regulated. Primary aluminium alloy is produced in SALCA Region 2 with a rainfall of twice the average South African rainfall [28], and water quantities for industrial usage are therefore readily available.

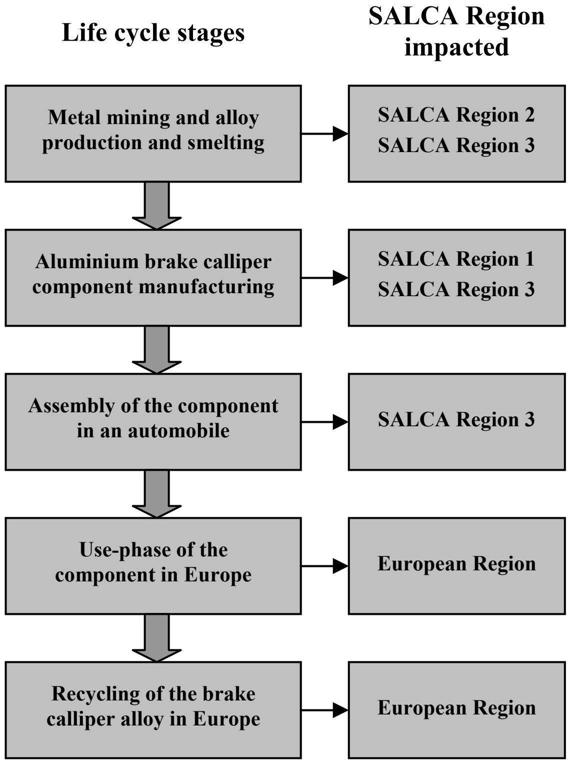

Figure 5: Life cycle system of brake callipers

Table 3: South African impacts of the life cycle

Life cycle stage	Environmental impact
Metal mining and alloy production and smelting	Water resource impacts due to mineral processing activities (SALCA Region 2) and energy (electricity) requirements (SALCA Region 3). Regional and global air resource impacts due to mineral processing activities and energy requirements. Waste disposal to land due to mineral processing activities electricity generation. Fossil fuel requirements for energy (SALCA Region 3). Processing of other required minerals in the component, e.g. steel springs, have environmental impacts to a smaller degree in SALCA Regions 3 and 4.
Aluminium brake calliper component manufacturing	
Assembly of the component in an automobile	

Although European Life Cycle Impact Analysis (LCIA) methods do not consider these impacts to be as important (after normalisation), compared to the impacts on air and mined resources [26], a South African region-specific evaluation could indicate these stresses on the available natural water resources to be of significance.

3.2. Air resources impacts

The South African impacts on air resources through the life cycle of an aluminium brake calliper can be allocated to the production of ingots and the alloy, the casting and assembly of the components to a minor degree, and the electricity requirements for material production, and component manufacturing to a lesser extent. The main pollutants of concern are:

- Global warming gases, especially CO_2 from electricity generation and perfluorocarbons from the ingot production.
- Metals and particulate emissions from materials production and electricity generation.
- SO_2 releases from the primary ingot production and electricity generation.
- NO_x and organics emissions from electricity.

Although these pollutants are of concern and constantly monitored in terms of ambient air quality [2, 29], the regional focuses are more directed towards water and land quality issues [11, 29]. Again, this is contradictory to what a typical available LCIA methodology would indicate [26]. Also, from a life cycle perspective, the main impact on air resources associated with the brake calliper can be found in its use-phase, which is either in a region external to South Africa (as with this case study), or in multiple regions of South Africa.

3.3. Land resources impact

The principal unit processes of the aluminium brake calliper product's life cycle do not have a major impact on land resources. The raw materials for the production of the alloy, i.e. bauxite and magnesium typically produced from dolomite, are imported. In comparison to the weight of the required aluminium alloy, other materials are of relative unimportance. However, the extraction of coal, often from open pit mining, for electricity generation is often omitted. Although SALCA Region 3 is characterised with large coal reserves, the scaring of surface lands due to the extraction will require long-term rehabilitation, which must be incorporated into the evaluation of a supply chain system. Furthermore, the electricity generation in South Africa results in the disposal of large quantities of ash, although these heaps are reasonably inert. Ashes heaps consequently represent a land use problem in SALCA Region 3.

3.4. Mined resources impact

As with the land resources, the most important unit processes related to the case study's product, does not have a large impact on South African mined resources. However, using LCIA methodologies shows this category to be the most important impact [26], although the fuel required during the use-phase constitutes the main reason for the large impact (more than 90 %). The only other mined resource of importance is again coal as fossil fuel for electricity generation. Liquid fuel, in the form of diesel, for transportation is also dependent of coal resources but plays a minor role. As stated in section 3.3, the coal usage results in the depletion of large reserves in SALCA Region 3.

4. CASE STUDY 2: LEATHER COMPONENT

The second case study focuses on the life cycle of a passenger vehicle's leather seat manufactured in South Africa, also for export purposes. The leather sector, and especially the supply to the OEMs, comprises a substantial part of the South African textiles industry [30]. The environmental impacts associated with leather manufacturing have also recently been highlighted in South Africa, specifically the tannery processes [31]. However, the complete life cycle of leather in South Africa and its related region-specific impacts must be understood, in order to define a complete environmental profile of the supply chain and identify potential problematic areas. The leather life cycle (Figure 6) has been evaluated with conventional LCIA methodologies [32]. Again, secondary unit processes, e.g. transport and energy supply, are not shown but have been included in the assessment. The key environmental concerns are indicated in Table 4. The complexity in evaluating the environmental burdens of the leather life cycle lies in the multiple regions involved to supply the necessary leather, depending on the respective season.

4.1. Water resources impact

The impacts on water resources of the leather industry are considered significant, especially the chromium processes relating to the tanneries [33]. In addition, the farming and abattoir unit processes required in the primary life cycle should also be evaluated with reference to the SALCA Regions:

- Cattle farming occur in all regions of South Africa, but the highest intensities are in the central (SALCA Region 4) to east (Regions 1 and 2) and north (Region 3) provinces with a high variability in the rainfall between the affected regions. Two cattle hides are required per leather seat, amounting to water use in excess of 50 000 litres over a two-year period [32]. However, the quantity is variable and needs to be allocated between the hides and the meat, which have similar economic values.

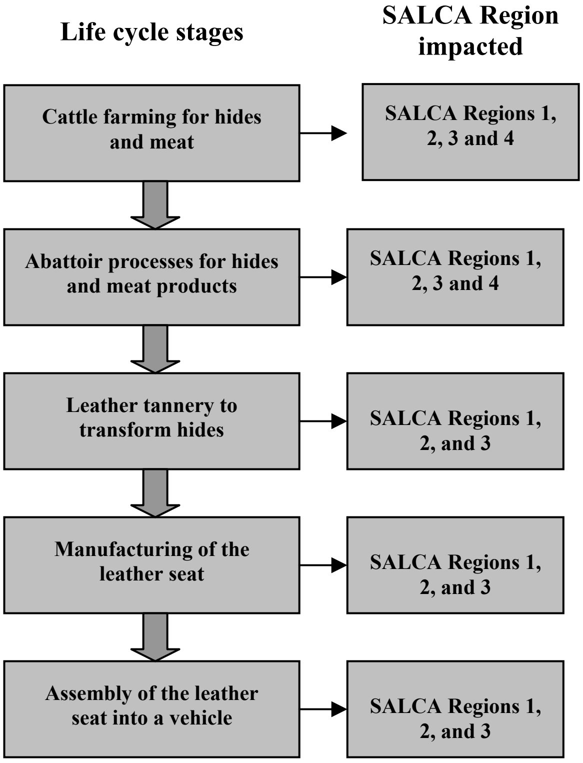

Figure 6: Life cycle system of leather seats

Table 4: South African impacts of the life cycle

Life cycle stage	Environmental impact
Cattle farming	Water resource impacts due to farming, abattoir and tannery activities, as well as energy (electricity) requirements (SALCA Region 3). Regional and global air resource impacts due to energy requirements (SALCA Region 3), as well as metallurgical processing for additional seat materials. Land usage for farming and waste disposal to land from the abattoirs (all SALCA Regions), tanneries SALCA Regions 1, 2 and 3) and electricity generation. Fossil fuel requirements for energy (SALCA Region 3). Processing of other required minerals in the component, e.g. steel alloys, typically in SALCA Regions2, 3 and 4.
Abattoir	
Leather tannery	
Leather seat manufacturing	
Assembly of the seat into a passenger vehicle for export purposes	

Additional impacts on ambient water qualities during farming are the result of fertilizers (KAN comprising mostly of ammonium phosphates) and insecticides (acarides consisting of flumethrin and piperonyl butoxide).

- The abattoir unit process requires approximately 2 000 litres of water per carcass, resulting in wastewater in excess of 1 500 litres [32]. These must again be allocated between the hides and meat products. Abattoirs are found in all areas where cattle farming occur, and the current stress on the water resources in a region must be taken into account, e.g. water supplies in the northern catchments (SALCA Region 3) have a negative balance in many cases, as do some catchments that supply the eastern areas of SALCA Regions 1 and 4, while water is in abundance in SALCA Region 2 [13].
- The tanning process requires in excess of 38 000 litres of water per 140 kg Grain leather [32]. A number of chemical substances, including salts, acids and chromium oxide, are used in the process with ensuing effluents (same order of magnitude as the processing water) comprising of solids, etc. with a high pH value and oxygen demand characteristics. Most importantly are the concentrations of chromium (III) and (VI), which are highly regulated and important toxins for aqueous ecosystems [33, 34].

Other impacts on South African water resources arise from the generation of electricity, primarily in SALCA Region 3, as discussed in section 3.1.

4.2. Air resources impact

The main air pollutants are the consequence of electricity generation with attributes similar to those described in section 3.2. Additional impacts of lesser importance include:

- Diesel combustion for farming vehicle purposes.
- Coal-fired boilers to produce steam for the abattoir and tannery processes.
- Ammonia, SO_2 and dust from the tanning process.

In general, the impacts on regional and global air resources due to the leather seat product are not considered to be of significance in South Africa [32].

4.3. Land resources impact

Impacts on land resources arise from the land surface area used during farming and the disposal of wastes, i.e. from the abattoir, tannery and electricity generation processes. In terms of the former, the different regions of South Africa have diverse grazing capacities, ranging from less than one hectare per Large Stock Unit (LSU), such as cattle, in wet regions, to 24 LSUs in drier regions [35, 36]. For areas where cattle farming are most popular, a value of 3 hectares per hide has been used [32]. It is therefore imperative that the carrying capacity of a region is taken into account in an evaluation of farming activities, which will influence the rehabilitation rate and consequent biodiversity of terrestrial systems. Generated wastes throughout the life cycle also have impacts in terms of land use, i.e. land filling as a means of disposal, but the soil and groundwater contamination potentials of different waste types are of increasing importance and regulated accordingly [37]. As stated in section 3.3, the ash from electricity generation is rather inert and the quantities attributable to the leather industry quite small, and the main focus should therefore be on the abattoir and tannery processes. In the case of the abattoir, the primary concerns are connected to the organic waste material, carcases, and dewatered rumen, although solid wastes from the treatment of the wastewater effluent, with soaps, disinfectants, etc. are also important. Similarly, the wastewater effluents from tanneries contain solids with adhered organics (fats and oils), chemicals (especially nitrogen-containing compounds) and highly toxic substances, such as chrome (VI). Although these are typically of general concern at a national level, the background concentrations of certain substances must be regarded, e.g. ambient metal concentrations in certain regions of South Africa are above international standards due to mining and other activities [38].

4.4. Mined resources impact

The impact on South African mined resources are not extensive. Coal is utilized as fuel for boiler operations in the leather life cycle system. The majority of collieries are found in SALCA Region 3 and the transported coal supplies therefore primarily have impacts on the reserves in this region.

5. CONCLUSIONS

Environmental Management Systems (EMS) are increasingly pressurised to focus on the supply chain of global market products [39]. This is especially true for OEM's, and suppliers in the automotive value chain are compelled to adhere to certain standards set by customers [40]. The South African manufacturing sector contributes progressively more to the global automotive market and local suppliers understand the need to conform to these international practices. From a sustainable development perspective for OEM's, however, a responsible approach is required to assess the environmental impacts associated with products imported from South Africa. This paper suggests that an environmental evaluation should be region-specific in a South African context, whereby additional stresses of a product supply system is determined on current water, air, land and mined resources qualities for four SALCA Regions.

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