PRODUCT CARBON FOOTPRINT ANALYSIS FOR THE PACKAGING PROCESS OF RETURNABLE GLASS AND PET CONTAINERS FOR A SOUTH AFRICAN CARBONATED SOFT DRINKS BUSINESS

Ivan Ivanov

A research report submitted to the Faculty of Engineering and the Built Environment, University of the Witwatersrand, partly in fulfilment of the requirements for the degree of Master of Science in Engineering.

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Declaration

I declare that this research report is my own unaided work. It is being submitted to the Degree of Masters of Science in Engineering (50/50) to the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination to any other University.

Ivan Ivanov

1st day of June, 2016

Abstract

Non-renewable resources are becoming scarce and current Global Warming Potential (GWP) values are rising. In an effort to promote a successful shift towards a "greener' planet, governments worldwide are developing policies, which enforce businesses to contribute to the effort. One such policy is the potential upcoming carbon tax (measured in weight of CO_2e) in South Africa. As a result, industries need to carefully analyse and understand their core processes and their impact on the environment to ensure that their operations have the lowest environmental cost possible. One such industry in South Africa is the fast growing Carbonated Soft Drinks (CSD) beverage packaging industry. CSD are packaged in both Returnable Glass Bottles/Glass (RGB) and PET containers. The Product Carbon Footprint (PCF) of the CSD packaging process for 300ml Glass and 500ml PET containers was of particular interest. Review of academic literature revealed that no similar research has been conducted previously in South Africa. International studies on PCF, which vastly use the (ISO 14040/14044, 2006) for their method, were found to have conflicting results and conclusions regarding the "greenness" of the two types of containers both with respect to the overall GWP of each and the percentage contribution of the packaging process life cycle stage to the total environmental impact. This is mainly because such studies are region and technology specific. A study was therefore required to understand the implications the business' Glass and PET CSD packaging process has on its GWP and hence carbon tax. The GHG (Green House Gas) Protocol PCF guideline (World Resource Institute, 2013) was used to construct the method for this research to ensure best practice, which would allow the study to be expanded into a full blown Life Cycle Assessment (LCA) as future work. It was found that the 500ml PET packaging process draws 100% of its Cumulative Energy Demand (CED) from purchased electricity (generated by burning coal) and has a GWP of 65 147 gCO_2e/hl (hectolitre), which is 4.5 times less than that for 300ml Glass (294 173 gCO_2e/hl) which has 71% of its emissions resulting directly from coal fired boilers on site. A dynamic model analysis revealed that packaging in larger containers results in a significant GWP reduction per volume for both Glass and PET containers. It was recommended that short term the business needs to focus on optimising its packaging lines' equipment, work with suppliers on reducing the weight of the raw materials used for the packaging containers manufacture and promote rate of return of its Glass.

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Acknowledgements

This study could not have been successful without the seamless co-operation of personnel from the selected South African carbonated soft drinks manufacturing business as well as the continuous and valuable support by Mr Dieter Hartmann.

Proprietary and Confidentiality

The carbonated soft drinks manufacturing business selected for this study shall remain anonymous. In line with the ethics associated with this research, the business' identity and/or any of its employees' names have been omitted. Furthermore, sensitive information about the business, such as sales, is not disclosed.

Acronyms and Abbreviations

BM – Blow Moulder

Bph – bottles per hour

CED – Cumulative Energy Demand

CO_2e – Carbon Dioxide equivalents

CSD – Carbonated Soft Drink(s)

FBI – Full Bottle Inspector

FLT – Forklift

GHG – Greenhouse Gas

Glass – returnable glass container. Used interchangeably with RGB

GWP – Global Warming Potential

hl – Hectolitre

HP – High Pressure

KPI – Key Performance Indicator

LCA – Life Cycle Assessment

LCI – Life Cycle Inventory

NRB – Non-Returnable Bottle

OEM – Original Equipment Manufacturer

PCF – Product Carbon Footprint

PET – Polyethylene Terephthalate

RGB – Returnable Glass Bottles

SKU – Stock Keeping Unit

SSD – Sparkling Soft Drink(s), same as CSD

SW – Shrink Wrapper

1. Introduction

1.1 General research project rationale

Due to the rapid rate of non-renewable resource depletion and ever increasing Greenhouse gas emissions, opportunities for carbon footprint reduction are of interest internationally. Industrial processes use electricity which emits CO_2 due to the combustion of fossil fuels (e.g. coal) and hence contribute to the global warming of the planet.

In an effort to enforce businesses to be more environmentally conscious, South Africa is considering the introduction of carbon tax regulation to all major sectors of the country's economy in the near future. One such contributor in the consumption of non-renewable resources and GHG emissions is the manufacturing sector, because of its numerous energy intensive processes. Therefore, businesses in this sector need to better understand what their carbon tax would be as well as how they can strategize to reduce it, in particular, the carbon footprint of a carbonated soft drinks packaging process, which is in either returnable glass or PET bottles. Above all, the Cumulative Energy Demand (CED) and Global Warming Potential (GWP) due to the packaging process of PET and returnable glass containers/bottles are of interest.

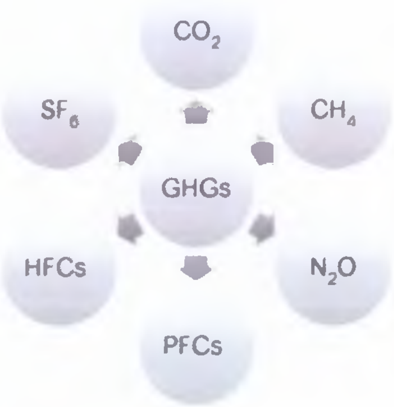
1.2 Purpose of the study

With the potential upcoming carbon tax regulation in South Africa, there will be a need for the selected CSD manufacturing business to better understand the global warming impact its core operations have on the environment and therefore its potential carbon tax cost. This will help the relevant stakeholders develop appropriate carbon emissions reduction strategies. The proposed research study will seek to quantify the environmental impact (Product Carbon Footprint) of the packaging process of, on the one hand, returnable glass and on the other hand PET containers respectively in a typical CSD manufacturing business in Gauteng, South Africa. This analysis will investigate cumulative energy demand (CED) and its links to carbon footprint impact in terms of GWP, during the packaging process of the two types of containers. The business may use the results of the study to understand how the usage of PET and Glass in its packaging process contributes to prospective carbon taxation. The study will also provide the business with an understanding of how the usage of Glass and PET on its packaging lines affects the country's carbon emissions in terms of fossil fuels burnt to generate electricity. By understanding the aforementioned implications the business will be able to make strategic decisions with respect to the choice of packaging container used in its packaging process.

1.3 Research background and motivation

Human activity results in "unnatural" processes which emit GHGs, such as the burning of fossil fuels to generate electricity. The length of time a GHG remains in the atmosphere as well as its ability to absorb energy are the two main factors which determine how strong a GHG affects the Earth's climate. The GWP is calculated by considering both of these factors. GWP for a GHG is expressed as an equivalent mass of CO2, which has the GWP of 1. The higher the GWP number is for a process the greater the impact of the Earth's climate will be. (United States Environmental Protection Agency, 2015)

An accurate carbon footprint is determined by taking into account all the GHGs. "The use of global warming potentials is central to greenhouse gas accounting and reporting…thus allowing for comparison between emissions totals, and facilitating the development and implementation of mitigation and reductions strategies and initiatives." (Emission Factors, 2014) Figure 1 shows the most central GHGs to climate change: (Shailesh, 2012):



Carbon dioxide (CO_2)
Methane (CH_4)
Nitrous oxide (N_2O)
Hydrofluorocarbons (HFCs)
Perfluorocarbons (PFCs)
Sulphur hexafluoride (SF_6)

Figure 1: Greenhouse gases (Shailesh, 2012)

Fossil fuels, which produce Greenhouse gases (GHG) when burnt, are non-renewable because the world has a limited capacity available and hence using fossil fuels for energy generation is not sustainable. (BBC UK, 2015) Example of some of the most used non-renewable resources include: coal, oil and natural gas. Different methods are used to estimate the fossil fuels left on the planet. Also the available methods are estimates and are based on assumptions which are heavily influenced by economic, seasonal and temporal factors. (BBC UK, 2015) Figure 2 shows an estimate for the length of time left of the planet's major fossil fuels. (Fastcoexist, 2015)

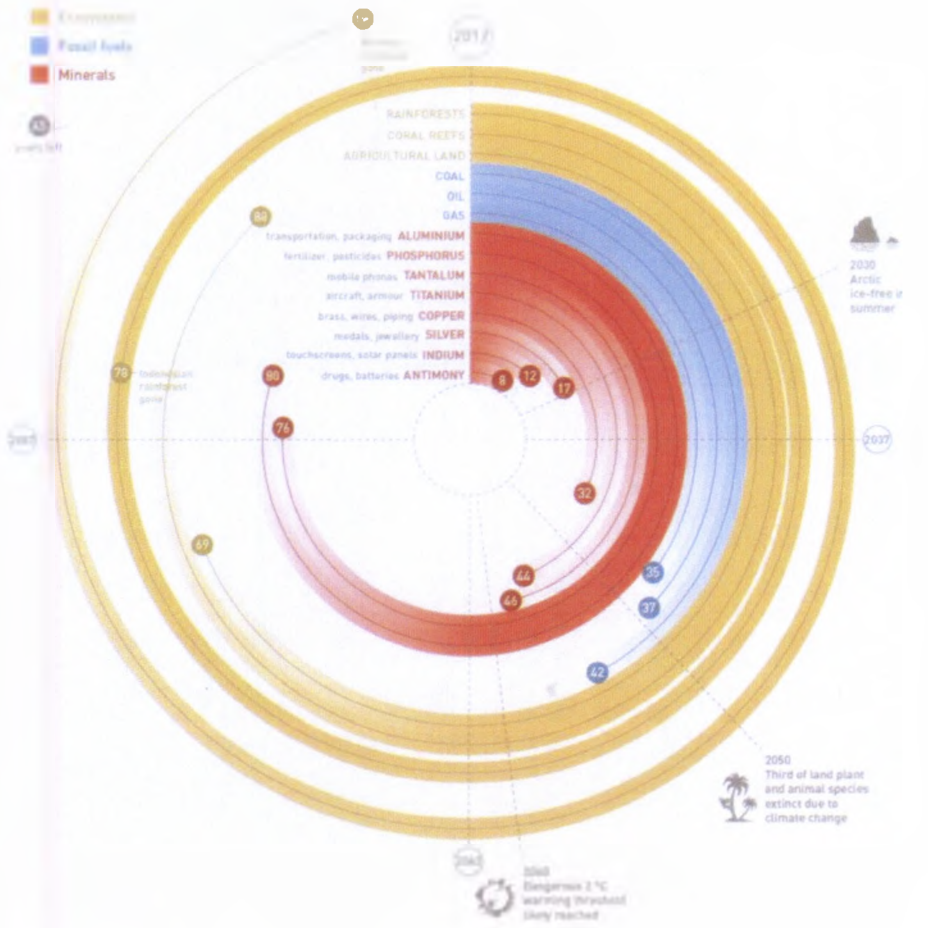


Figure 2: Estimated remaining world supplies of non-renewable resources (Fastcoexist, 2015)

As can be seen from the figure above, the estimated years of coal, oil and natural gas are 42, 37 and 35 respectively.

Table 1 shows the estimated number of years left of major fossil fuels using a different estimation method:

Table 1: Estimated length of time left for major fossil fuels (BBC UK, 2015)

Fossil fuel	Time left
Oil	50 years
Natural gas	70 years
Coal	250 years

Although different estimates are obtained by each method, the fact of the matter is that fossil fuels will run out eventually in the near future and actions need to be put in place now to ensure a sustainable planet for future generations.

There are two ways in which fossil fuel depletion can be reduced. The first is by reducing the fossil-fuel-generated energy demand and the second is by increasing the supply of renewable energy. (BBC UK, 2015). In both cases an understanding of the CED for a process is required beforehand. It is therefore of interest, especially big, energy intensive corporations, to consider the impact processes' CED has on consuming these very limited non-renewables.

A few ways have been identified regarding how companies can reduce their environmental impact. Examples include using alternative to natural resources products, making use of recycled materials and considering all parts of the business activities and evaluating their environmental impact. (Queensland Government, 2014). "Reducing the impact on the environment and conserving non-renewable natural resources is not the only benefit of running an environmentally friendly business". (Queensland Government, 2014). Environmentally conscious companies enjoy numerous benefits as well. Cutting costs is considered the major benefit of earth-friendly organisations. Business costs tend be reduced by simply avoiding, reducing, reusing and recycling non-renewable resources. (Queensland Government, 2014). Adopting green policies will help businesses attract new customers. (Queensland Government, 2014). Greener companies tend to be more sustainable than their counterparts. This is mainly due to greater independence from natural resource price fluctuations, climate change and other similar factors which less-green competitors may suffer from. (Queensland Government, 2014). (Zokaei, 2013) Points out that companies that tackle environmental waste can identify and eliminate some of their economical waste as well, thus increasing their profit margins.

South Africa is the 14th highest emitter of greenhouse gases in the world. (South Africa Info, 2015) The country is a signatory to the Kyoto Protocol, thus committing to reduce its emissions of greenhouse gases. (South Africa Info, 2015) Furthermore, the government has rolled out a National Development Plan (NDP) which main focus is the sustainable development of the country. (South African Government, 2015). The South African minister of finance has released a draft on the long discussed carbon tax legislation for public comments in late 2015 and the goal of the government is to pass that regulation in 2016. (Minister of Finanace, 2015) The main goal is to reduce greenhouse gas emissions by 34% by 2020 and 42% by 2025. (Minister of Finanace, 2015) This new legislation is will affect all South African businesses both directly and indirectly. With reference to appendix A, most industries in South Africa will be directly affected by the new legislation. However, other industries will be indirectly affected because of upstream supplier costs such as electricity suppliers. Therefore businesses have to take into account their entire supply chain as well as their operations to mitigate the costs associated with the potential introduction of carbon tax legislation. A thorough understanding of areas where the business will be subject to tax requires identification in order for companies to effectively start planning their move away from carbon reliance. (Parker & Gilder, 2015)

Furthermore, this carbon tax will be calculated based on the fossil fuel or non-renewable inputs that result in greenhouse gas emissions. (Minister of Finanace, 2015), (Parker & Gilder, 2015). The cost will be measured in terms of CO_2e (carbon dioxide equivalent). It will consist of R120/tonne of CO_2e. There will also be an annual raise of 10%/year. However, there will be tax relief regulations, which may result in the effective cost of carbon tax to the business to be between R12 – R48/tonne of CO_2e. (Parker & Gilder, 2015) Because this rate is significantly less than the statutory rate, it's in the business' best interests to understand how their products relate to the carbon tax. Also, companies may not be able to incorporate the increase in cost of manufacture due to the carbon tax liability into the price of their products, because of customer agreed contracts and other market regulations. Hence it is important for all businesses in South Africa to investigate their operations' product carbon footprint. The aforementioned findings apply to the carbonated soft drinks manufacturing business in South Africa and as such this study will play the part of a valuable reference to the company under investigation.

Table 2 shows South Africa's non-renewable and renewable resources contribution to total energy generation: (World Nuclear Association, 2015).

Table 2: South Africa's sources of energy generation

Type	**Generating Capacity (GWe)**	**% Contribution**
Fossil Fuels (Coal)	34.3	85%
Nuclear	1.8	4%
Other	4.4	11%
TOTAL	**40.5**	**100%**

From Table 2 it is evident that the power stations generating the largest portion of electricity for the South African grid consume non-renewable resources (coal) (85%). This is important to note as the company under investigation in this project uses energy from both the national grid in the form of purchased electricity as well as self-generated energy from site-installed coal-fired boilers. The CSD industry was considered to be of importance because on the African continent CSD demand is expected to experience a steady trend growth of 4.2% per year. (Canadean, 2013) Also, given the current soft drinks consumption in South Africa, which is also the 10th largest consumer of soft drinks is the world; this annual 4.2% growth translates to a massive additional consumer demand, which the beverage industry must satisfy. (Statista, 2015)

South African businesses are placing a major focus on reducing their carbon footprints and improving efficiencies. The company has recognised that its operations directly impact on the planet's climate. A study has concluded that a 1 C° increase in temperature results in 10% decrease in farming productivity. (ABI, 2015) Hence, the study concludes that waste management and the introduction of energy technologies should be at the forefront of any company's carbon reduction initiatives. Furthermore businesses are advised to develop the following goals for their packaging operations amongst others: (ABI, 2015)

- "To adopt a holistic approach to sustainable packaging management
- To increase use of recycled content and sustainable materials
- To reduce the amount of packaging raw material consumption.
- To actively participate in activities that encourage post-consumer waste recovery
- To optimise packaging design to enable recycling or re-use" (ABI, 2015)

CSD in general are packaged in Glass, PET or Aluminium containers. Prior research (Franklin Associates, 2009) (Paster, 2007), (Pretium packaging, 2012) has investigated the "greenness" of Glass vs. PET bottles to determine which is environmentally friendlier in terms of overall energy usage throughout its respective life cycle. Evidence points to the fact that PET is fast becoming the better option for reasons such as its lightweight composition and better energy efficiency during its packaging process as well as its low transport cost when compared to its Glass equivalent.

Table 3 presents some facts about PET and Glass in terms of their composition and impact on the environment. (Paster, 2007)

Table 3: PET vs. Glass facts comparison (Paster, 2007)

Description	**PET**	**Glass**
Abiotic materials (minerals and fossil fuels) used (g/g)	6.45	3.04
GHG's emissions (g/g)	3.723	0.716
CO2 for every 1000 units shipped 1000km	33.5	224.9

Table 3 shows that glass containers have a lower initial manufacturing environmental impact whilst PET is superior to Glass on transportation costs. (Paster, 2007) Still this research cannot be used to clearly justify the usage of PET over glass containers on the packaging lines for a South African CSD manufacturing business. Also little part of the research can be directly used by the business to better understand the role its packaging container choice has on the environment in terms of carbon footprint, because majority of the research is conducted for organisations outside of South Africa and no general conclusion about the environmental cost of a system can be made. (Flanigan, et al., 2013)

In general, the argument that cost based selection by companies may reduce making of environmentally friendlier choices still exists. It is therefore important to investigate the carbon footprint of the CSD packaging process in PET and Glass from a neutral point of view.

2. Literature Review

The purpose of this section is to identify gaps in the existing literature with respect to determining the product carbon footprint of the CSD packaging process for Glass and PET for a South African business. These gaps are used in developing the problem statement and objectives for this research.

2.1 Methodology for literature review

The following literature review methodology is followed to ensure credibility and originality of the selected topic:

1. Review current literature to determine what work has been done on determining the Product Carbon Footprint (PCF) for CSD packaging process in Glass and PET in South Africa
2. Identify and discuss potential gaps between the reviewed literature and research project topic

2.2 Review of literature and gaps identification

"Life Cycle Assessment (LCA) is a quantitative evaluation of the environmental performance of a product system across its life cycle. While LCA does not represent a complete set of potential environmental, social, or economic impacts to be optimized for packaging, it provides a replicable and rigorous methodology for evaluating several key environmental metrics of priority to the sector and its customers" (Flanigan, et al., 2013), for example identifying environmental hot spots, understanding trade-offs between alternative products. LCA is an internationally used approach when assessing environmental impact of a given product or process. "Life Cycle Assessment helps encourage a transition away from focus on single-issue environmental priorities and provides insurance that environmental burdens are not shifted from one life cycle stage to another (e.g., from manufacturing to raw material production). In other words, LCA results make it more difficult to make decisions that are out of context for the product or environmental impacts being optimized." (Flanigan, et al., 2013) For example it would be unnecessary to investigate the environmental impact of the CSD packaging process for a plastic container vs. a Glass container, if an LCA has found that the raw materials required to manufacture PET require a lot more energy than the ones for Glass in which case comparing the packaging process environmental impact of the two types of containers would be of little value for the decision making process of relevant stakeholders. However, a study should still be undertaken when a business is trying to evaluate the PCF of its product/service.

ISO 14040 and 14044 are specifically drafted to provide a best practice approach when conducting LCA studies, which can be used for organisations in both developed and developing economies. (Flanigan, et al., 2013) In summary, there are four phases one should take into account: (Flanigan, et al., 2013)

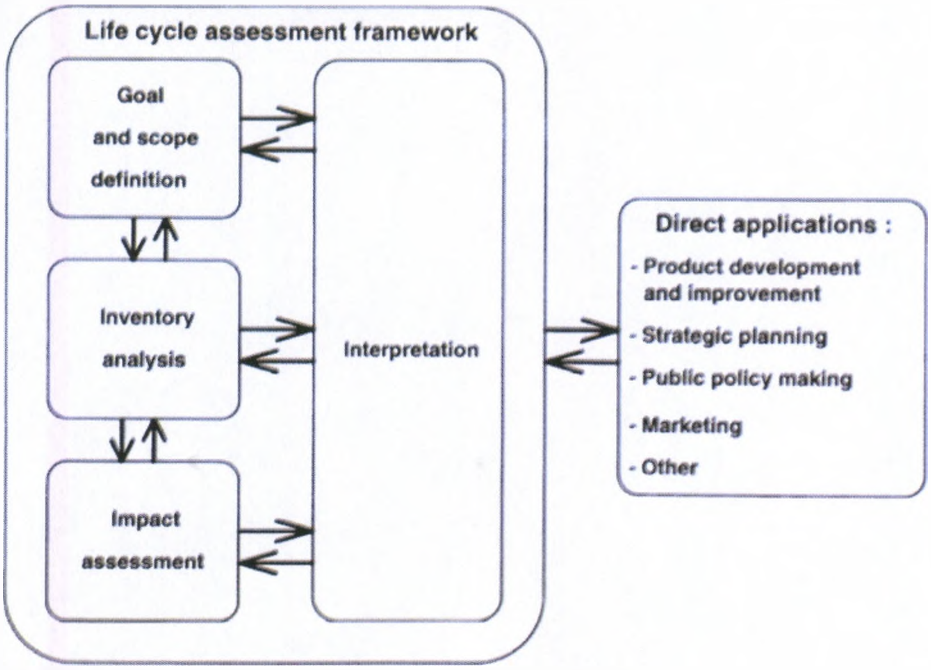


Figure 3: LCA phases (ISO 14040/14044, 2006)

- Goal and scope definition – system parameters are set and functional unit defined (ISO 14040/14044, 2006)
- Life cycle inventory analysis – a list of resources consumed and emissions generated throughout the product's life cycle within the scope of the study is compiled (ISO 14040/14044, 2006)
- Life cycle impact assessment – inventory from previous step is characterised based on potential of contribution to environmental concerns such as climate change and resource depletion. (Goedkoop, et al., 2009) have developed characterisation methodology which is vastly used by researchers in the field (Flanigan, et al., 2013)
- Furthermore, it is essential that the correct impact categories are selected for the analysis. Choosing too little and or the wrong impact categories may result in inaccuracies. (Flanlgan, et al., 2013)
- Interpretation – results are evaluated in terms of system boundaries, collected data and assumptions made (ISO 14040/14044, 2006)

Furthermore, any "LCA methodology should be amenable to the inclusion of new scientific findings and improvements in the state-of-the-art of the technology" (ISO 14040/14044, 2006).

Figure 4 shows a LCA for a typical packaging container with the major life cycle stages shown.

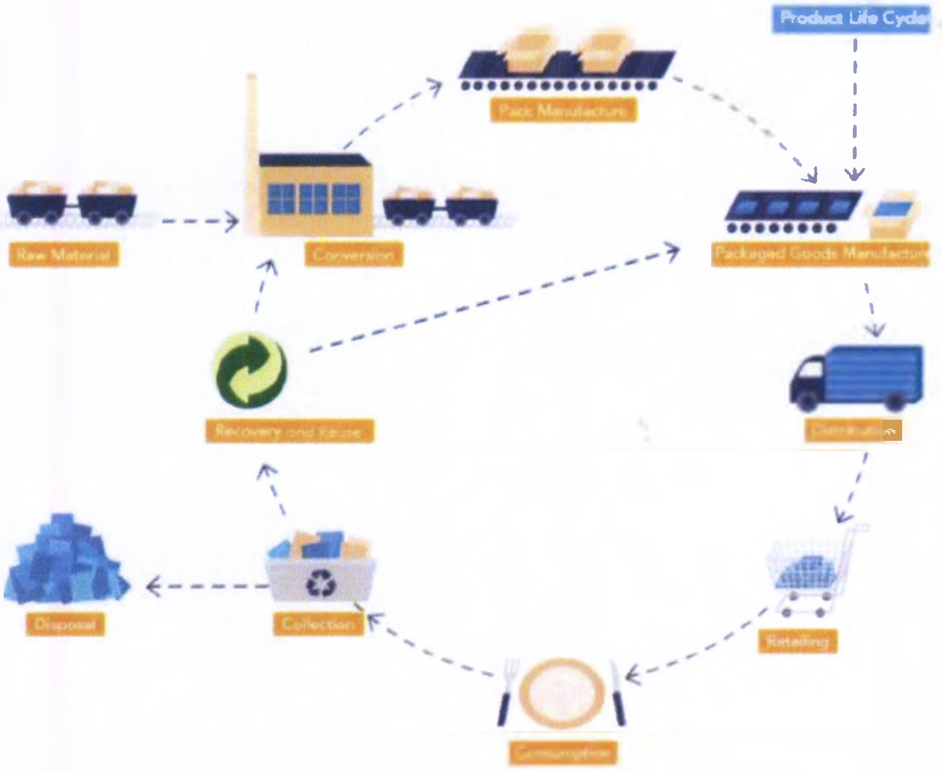


Figure 4: LCA stages for a typical packaging product (Flanigan, et al., 2013)

Highly automated machinery is the result of a demand increase for soft drink beverages over the past few decades. This has resulted in bigger, faster and higher quality machinery. (Hirsheimer, 2015) This machinery requires less people to run at the expense of consuming more energy. Figure 5 represents the major process blocks of a CSD packaging line together with its major supporting operating activities. (Hirsheimer, 2015) It is good visual illustration of all the major energy consumers required to package a SSD in a container. Also, it enables one to accurately determine the overall energy consumption required by a packaging line by summing the entire relative and directly contributing process blocks.

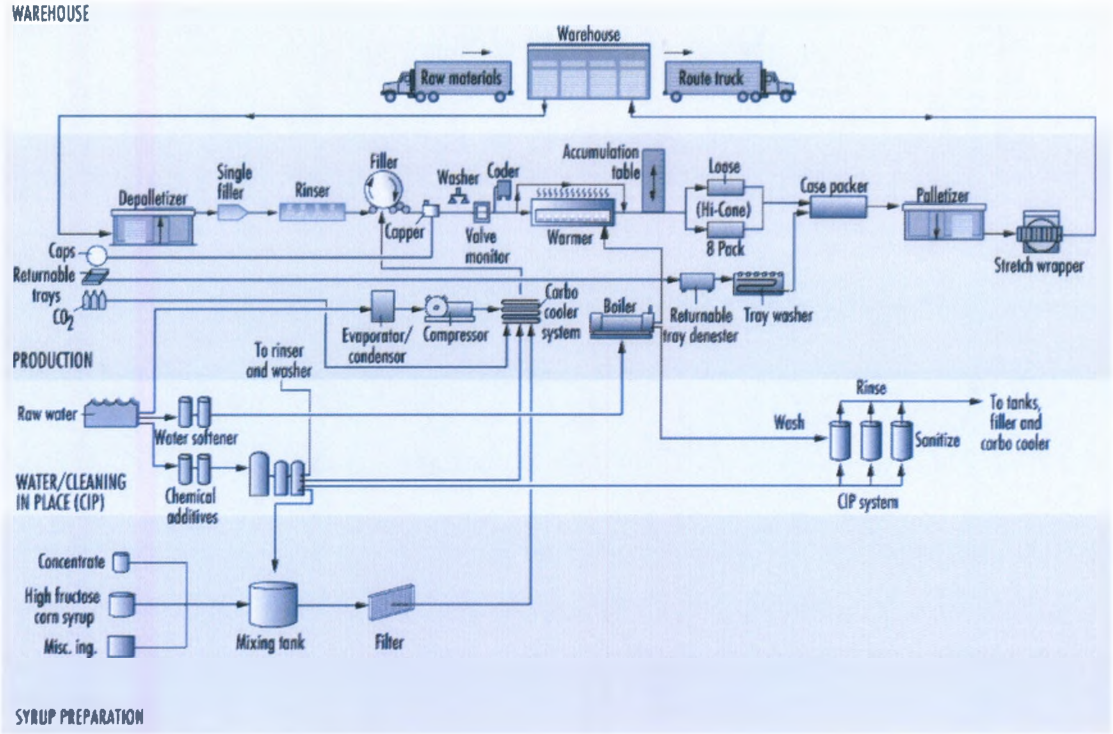


Figure 5: Process flow chart of basic bottling operations (Hirsheimer, 2015)

(Amienyo, et al., 2013), who make use of the guidelines provided by (ISO 14040/14044, 2006), have determined that in order to obtain accurate results, the energy related to the use of all type of secondary packaging material such as stretch wrap, crates, etc. as used on the different packaging lines need to be considered e.g. mapping of the process from a primary packaging container point of view and understanding all the energy required to produce the end product. For the Glass containers' packaging line, de-palletising the bottles, washing of bottles and crates, filling, capping and labelling of the filled bottles, re-crating, re-palletising activities need to be considered. For the PET container's packaging line blowing of PET pre-forms to form the final bottles, washing and drying, capping, labelling and stretch wrapping need to be considered. The energy required for the belt transport system on the two different packaging lines should also be factored in. (Amienyo, et al., 2013)

Furthermore, (Amienyo, et al., 2013) have used the ISO 14040/44 standards to conduct a cradle to grave study of the CSD production impact on the environment. Data for the study was obtained from a carbonated soft drinks manufacturer as well as from CCaLC, Ecoinvent and Gabi databases. Software tools have been used to develop the LCA modelling. The study has adopted the CML 2001 method for assessing the overall environmental impact. The scope of the proposed research does not contain a cradle to grave analysis, which renders the use of the software modelling tools used by (Amienyo, et al., 2013) impractical. Furthermore, the use of software provides a generic dataset, while this study will make use of real, site and packaging line specific data where possible. Furthermore, (Amienyo, et al., 2013) suggest that data concerning the packaging of CSD into the different types of containers must be obtained directly from the business under investigation to ensure the most accurate results.

(Flanigan, et al., 2013) have done a study, which has consolidated the "outcomes of existing research on environmental performance of packaging". The study's conclusions may be regarded to form the basis for future environmental impact assessment of packaging. In addition, the publication provides a detailed methodology for conducting LCA studies, including knowledge mining techniques. The focus of the publication is to provide best in practice guidelines, which can be used in assessing the environmental impact of packaging containers. Furthermore, the study highlights that optimal packaging design from an environmental performance point of view may vary according to packaging system inputs such as raw materials, product being packaged, and route of supply. (Flanlgan, et al., 2013) Hence, the findings of a study conducted in the USA for example cannot be directly applied to the South African business in question as there are many system parameters such as technological and geographical inputs which will differ between the two countries.

Qualitative and quantitate methods can be combined into a framework for the environmental assessment of a product/process. (Huang & Ma, 2004). However, the research has found that these two types of methodology do not yield consistent results. The majority of the literature (Flanigan, et al., 2013), (Franklin Associates, 2009), (Ghosh & Socci, 2012), (Gleick & Cooley, 2009), (Humbert, et al., 2009) available on LCA prefers the quantitative approach. Hence, quantitative methodology would be adopted by this research.

An effective approach done during a study conducted by (Steenwerth, et al., 2015) was to gather site specific data (material specifications, OEM technical specifications, utilities bill, etc.) and to interview key business personnel in order to best understand and quantify the manufacturing processes and their respective energy consumption requirements. A similar data gathering approach is selected for this research, because it will eliminate many general assumptions and will therefore yield more accurate and useful results, which are value adding and business specific.

In a study done by (Bieda, et al., 2015) only certain environmental aspects such as electric energy, steam, air, heat, and industrial water as well emissions of various GHG were considered in the life cycle assessment of a process. Another study by (Frischknecht, et al., 2015) has determined that the using the cumulative energy demand for a process is an effective way of determining the impact of a process on the environment, however one should take care when defining renewable and non-renewable energy as this definition can have significant impact on the results of the study.

(Humbert, et al., 2009) suggested that the best approach for undertaking an LCA analysis is by adhering to already developed ISO standards, which is a compilation and evaluation of the different inputs, outputs and potential impacts on the environment throughout a product's lifecycle. (Ecoinvent, 2015) offers an extensive database for modelling systems to evaluate their environmental impact from cradle to grave. However, the website does not offer an educational trial and was therefore not used for this study.

Furthermore, there are numerous environmental impact assessment factors which can be considered during an LCA study. These include CED (GJ), GWP (kg CO_2 eq.), ADP (kg SB eq.), AP (kg SO_2 eq.), EP (kg PO_4 eq.), HTP (kg DCB eq.)x(100), MAETP (t DCB eq.)x(100), FAETP (kg DCB eq.), TETP (kg DCB eq.), ODP (mg R-11 eq.)x(100) and POCP (g C_2H_4 eq.)x(100). (Amienyo, et al., 2013) From the aforementioned, (Humbert, et al., 2009) identified two environmental factors which are best suited for the comparison of the environmental impact of different types of products. Those are Global Warming Potential (GWP), which is measured in kg of CO_2 equivalent and Cumulative Energy Demand (CED), which is measured in kWh. The emission levels of the greenhouse gases (CO_2, CH_4, N_{20} and halogenated hydrocarbons) are expressed by the GWP. On the other hand the consumption of renewable and non-renewable resources energy accumulated throughout the different stages of the life cycle of a container is expressed by the CED. CED is related to the GWP because non-renewable resources, which generate GHGs, may be used for the generation of energy.

The topic for this research requires a quantification of the GWP for the CSD packaging process of Glass and PET for a South African manufacturer. The aforementioned discussion has been around the benefits of an LCA as well identifying the most suitable methodology when conducting such environmental studies. However a more specific branch of an LCA called Product Carbon Footprint is available for conducting environmental impact comparison studies. According to (Martin, 2014), there's a slight difference between LCA and Product Carbon Footprint (PCF) aka GHG emissions assessment. PCF "only assesses the global warming potential of an organization, product, project or service" (Martin, 2014) in terms of

GHGs and converts them to carbon dioxide equivalents, "whereas a life cycle assessment (LCA) assesses multiple environmental impact categories, which may include global warming, but may also include human health impacts, ecosystem quality, acidification, land use, etc." (Martin, 2014) The three most internationally used standards for conducting such a study are PCF: PAS 2050, ISO DS 14067, and the GHG Protocol (GHG Protocol - Corporate Accounting and Reporting Standards). The latter one is selected as a guideline for this research because it is intended for quantifying GHG emissions only for business activities and operations). (Martin, 2014)

Another distinguishable feature of PCF is that it considers all direct GHG emissions associated with a process (either owned or controlled), indirect GHG emissions from purchased electricity, heat or steam and all other indirect emissions such as waste disposal, transportation, etc. (Martin, 2014) (World Resource Institute, 2013)

Figure 6 summaries the internationally recognised steps in identifying and calculating GHG emissions for a given product or service:

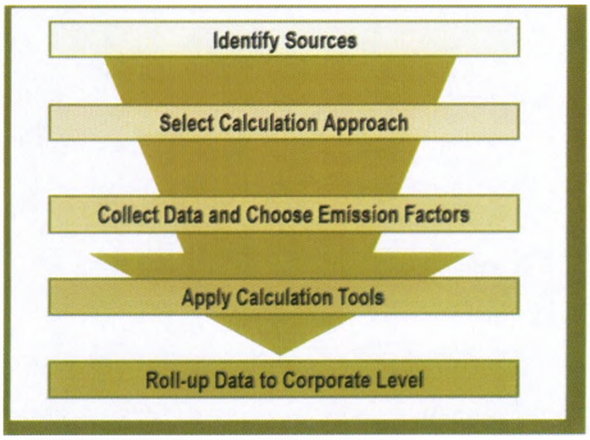


Figure 6: Steps in identifying and calculating GHG emissions (World Resource Institute, 2013)

Numerous existing LCA studies for Glass and PET focus on determining the environmental impact in terms of GHGs emissions. Such studies need to be reviewed because their findings may terminate the significance of this research, because it may be found that the question posed by this research has already been answered. The current research focuses mainly on one life cycle stage of Glass and PET containers used by the CSD packaging process only, as it would be viewed by the selected South African business. If the results of the current study show that the packaging process for Glass has a much lower GWP value than the one for PET, the logical business decision from an environmental point of view would be to convert all of its packaging lines to Glass. If however a full blown LCA for Glass and PET is done it may reveal that:

- The packaging process for Glass and PET is the least environmentally costly life stage for the two containers. Hence the decision for the business to convert to Glass may not be justified as supplier costs or other upstream business operations such as transportation of the Glass will be significantly higher than PET, because Glass is more environmentally costly in those upstream life cycle stages than PET. Also, a higher GHGs emissions for Glass upstream will result in higher supplier carbon tax which will result in higher Glass material cost to the business
- The overall environmental cost for Glass is much higher than the one for PET. If this is the case the business might be forced by external stimuli such as government and suppliers to convert all of its packaging lines to PET

Hence, before starting with the study, it is very important to review existing LCA for Glass and PET and to understand the overall environmental cost for Glass and PET as well as the contribution of the packaging process life cycle stage to this overall environmental cost.

In an American study, which has adopted the internationally recognised LCA methodology as specified by (ISO 14040/14044, 2006), PET (32MJ/16oz bottle) has a very similar total environmental impact to NRB (glass) (34MJ/16oz bottle). (CAE, 2005) PET has been found to be better for the environment in areas such as transportation, while glass is better in terms of container production and recycling. On the other hand a European study, also following LCA guidelines (Quantifying environmental impacts of Carbonated Soft Drink (CSD) packaging , 2009) has produced the following results:

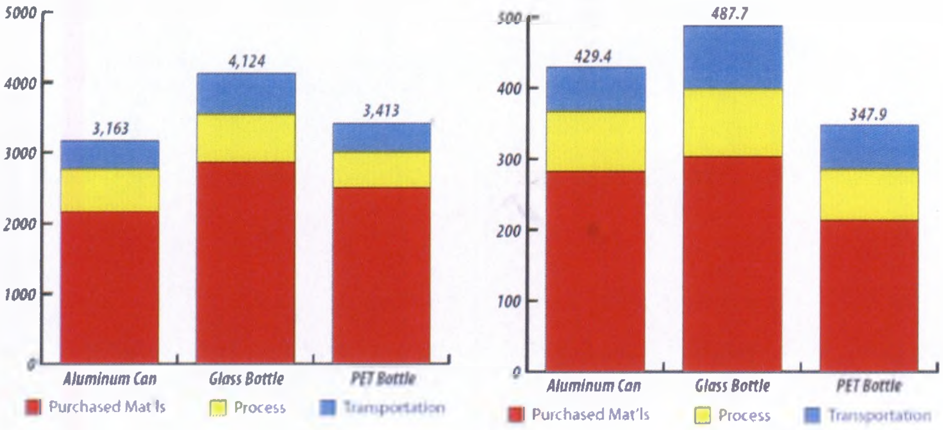


Figure 7: A - MJ/1000 units and B – GHG emissions (lbs. Co2e/1000units) (Quantifying environmental impacts of Carbonated Soft Drink (CSD) packaging , 2009)

The study focused on comparing PET, glass and aluminium cans in terms of their total energy consumption and total greenhouse gas emissions. In this study, both the overall MJ/1000 units (CED) as well as the lbs. CO_2e/1000 units (GWP) are lower for PET than for glass containers. The yellow part (process) for the CED and GWP, which refers to the packaging of the different types of containers, is approximately 10% less in favour for PET. Furthermore, the study did not consider returnable glass containers. The case study is also done in Europe and as such carries a lot of continent specific assumptions. It does not offer a true reflection of packaging container comparison, which can directly be translated to South Africa, because the facilities tested in the study use their own specific machinery, which draw power from a source, which may or may not use coal as its primary fossil fuel. It is evident that based on the assumptions and many other factors such as political, economic and situational, the container's "greenness" is expected to differ and applying the findings of one study to another would not provide stakeholders with accurate results.

An Australian study, adhering to LCA principles in line with (ISO 14040/14044, 2006), has determined that PET is worse for the environment than Glass if both containers' manufacture and their packaging is done locally. (Spenser, n.d.). Hence, geographical factors and local availability of fossil fuels play a significant role in determining the environmental impact of a product/process which again implies that studies conducted globally cannot be directly used by decision makers in South Africa.

Glass packaging has been found to benefit the environment because it can easily be recycled and reused. Re-use means that less fossil fuels are required for container fabrication. Transportation costs and cleaning requirements on the packaging lines have to been found to be the main reasons for the preference of PET over Glass containers, (Marsh & Bugusu, 2007) mainly because Glass is a much "dirtier" and unsafe process as a result of container breakages. However, the study does not in any way quantify the environmental impact of those cleaning requirements on the packaging lines for Glass. It is therefore of interest to understand what the impact of such systems is on the environment in terms of CED and GHG emissions.

A study conducted by (Franklin Associates, 2009), in the United States, has extensively made use of an LCA methodology by following (ISO 14040/14044, 2006) and has analysed the cradle to grave impact on the environment of glass, PET and aluminium containers, in terms of the solid waste generated, greenhouse gas emissions and energy consumption in the context of the CSD manufacturing industry in the USA. It has found that the majority of total energy for PET and glass occurs in the cradle to material and container fabrication life stage. Furthermore, (Franklin Associates, 2009) found that PET bottles resulted in less greenhouse gas emissions overall (77% less than glass). The study also found that the energy used for PET bottles totalled 11 million BTU per 3000l of soft drink vs. 26.6 million BTU per 3000l of glass. However, the study does not consider the energy required for the packaging of glass and PET. Hence, a business looking to determine its direct carbon tax contribution would fail to do so based on the findings of this study. Also, the study was conducted in the USA where the packaging raw materials manufacturing processes are not identical to the ones in South Africa. Although similarities exist, no two processes are identical and businesses use different technologies to produce their goods. For example the way energy is used and recovered in a CSD manufacturing plant in the USA would be different to the way energy is used and recovered in a corresponding South African plant. Hence, because of raw material supplier differences as well as transportation distances, the results of (Franklin Associates, 2009) cannot be generalised for all CSD manufacturers. Although the results can be used as a general guide they do not provide confidence for decision makers in South Africa. Secondly, the study was conducted in general for CSD manufacturers and it didn't focus on a single business and hence it's not company specific. Thirdly, the environment for the study is not identical to South Africa's. For example the power used in the USA could have come from a renewable power source such as hydro-electric generated energy. The market conditions are different (distance to from supplier of raw materials to manufacturing site, distance from manufacturing site to consumer and waste areas, etc.). Forth, the study takes into account the whole cradle to grave impact of PET and glass bottles, which has many variables (such as supplier manufacturing processes, country specific travel distances, etc.) that is cannot simply be translated to a business in South Africa. Glass could still be better than PET from packaging process point of view for a specific business. Also the study looked at single serving, non-refillable glass containers. No evidence is provided by the study regarding RGBs. Hence, an RGB might be greener than its PET equivalent.

(Gleick & Cooley, 2009) found that for a PET container the energy cost for packaging of water is 0.34% of the total energy cost that goes into the bottle. This result was calculated by using theoretical packaging machines' power consumptions for fillers and labellers only. A detailed analysis of the energy costs of all packaging line components was absent. However, an important recommendation of the study for future work was to investigate in more detail the energy consumption associated with the packaging process in order to better understand its impact on the environment as well as to identify potential energy saving opportunities.

In another European LCA for CSD manufactures, (Doublet, 2012) has concluded that refillable glass bottles have lower environmental impact than PET. Figure 8 below show the environmental impact contributions from each life cycle stage of glass and PET as found by (Doublet, 2012).

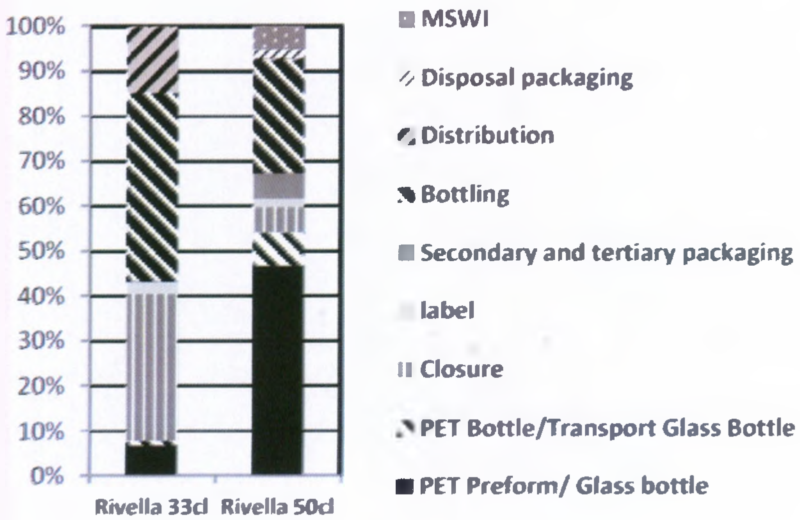


Figure 8: LCA results comparison for Rivella 33cl (returnable glass bottle) vs. Rivella 50cl (one way PET bottle) (Doublet, 2012)

"Bottling" (Doublet, 2012) i.e. CSD packaging process (50% of the total GWP for Glass and 20% of the total GWP for PET) has a significant environmental impact and hence an investigation into bottling will have a significant impact on the container's total environmental impact. Furthermore in another European study, the packaging stage of the LCA for Glass and

PET was also found to form a significant part of the total LCA energy. (Pasqualino, et al., 2011) Hence, considering only the packaging phase of the process in more detail can be expected to provide sufficient information for the business studied, which can be used to develop strategies focused on directly reducing the company's carbon tax. Also, any reduction made in this area would be in line with South Africa's GWP reduction policies. (Minister of Finanace, 2015)

A study conducted by (Amienyo, et al., 2013) following (ISO 14040/14044, 2006) in the UK has looked at the GWP for CSD from cradle to grave for containers of various sizes, which include glass and PET bottles. The manufacturing stage of the process has been found to account for up to 10% of the total energy mainly due to the resources required on the CSD packaging lines. (Amienyo, et al., 2013) 2L PET container has been found to have the lowest carbon footprint when compared to a non-returnable glass container. However, if the Glass containers are re-used its carbon footprint would be very close to that of the PET container, because less energy would be required for the packaging raw materials stage manufacture. Figure 9 summarises the results of the study.

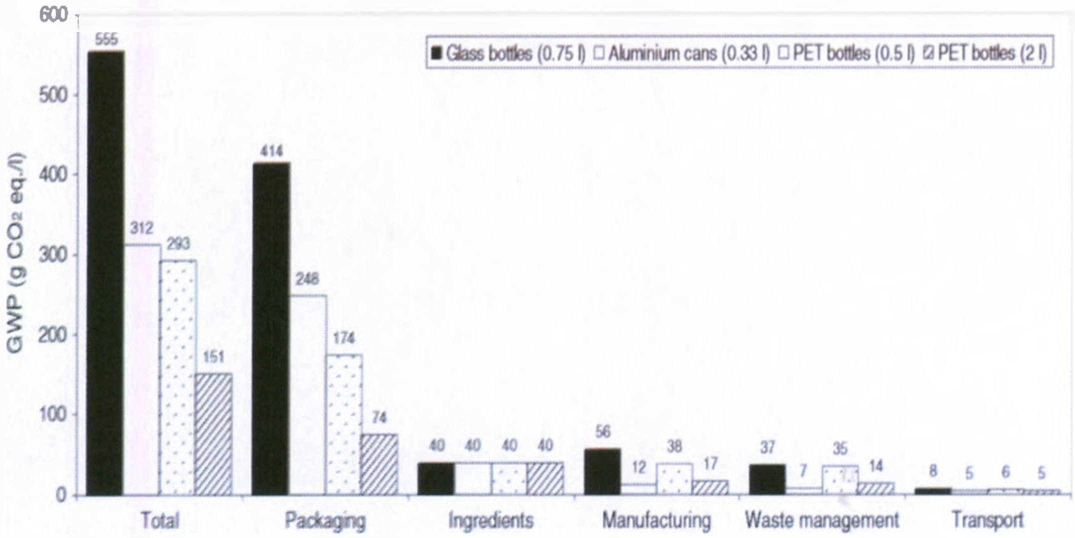


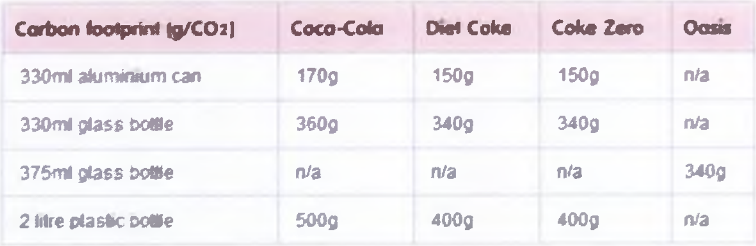
Figure 9: "Global warming potential of the carbonated drink for different types of packaging showing the contribution of different life cycle stages" (Amienyo, et al., 2013)

In this study, it is evident that the "Packaging" life stage, which in the study is defined as the stage where containers are manufactured from raw materials, is by far the most environmentally costly life state in terms of GHGs emissions for both glass and PET. The CSD packaging process stage (defined by the study as "Manufacturing") contributes a small amount to the total environmental cost for the different types of containers. (Amienyo, et al., 2013)

Because the study has been conducted in the UK it will not be accurate to translate the conclusions directly to a South African CSD manufacturer. This is because raw material supply and availability in the UK is different to the one in South Africa. Manufacturing technologies as well as transportation distances also differ between the two countries as no two manufacturing plants carry the same characteristics. Therefore a similar research in the South African context is required by the business, if an accurate comparison of the environmental impact for its CSD packaging process in Glass and PET is required.

PET has been found to impact the environment to the same degree as a Glass container if the Glass container is being re-used a certain number of times. (Vellini & Savioli, 2009). (Journey Staff - Coca-Cola, 2010) have also done an LCA study by adhering to (ISO 14040/14044, 2006) on the cradle to grave for a few of their most popular products. The results are shown in Table 4:

Table 4: Environmental footprint for Coca-Cola's bestselling products (Journey Staff - Coca-Cola, 2010)



Carbon footprint (g/CO2)	Coca-Cola	Diet Coke	Coke Zero	Oasis
330ml aluminium can	170g	150g	150g	n/a
330ml glass bottle	360g	340g	340g	n/a
375ml glass bottle	n/a	n/a	n/a	340g
2 litre plastic bottle	500g	400g	400g	n/a

(SABMiller, 2015) have done a comprehensive LCA study by applying (ISO 14040/14044, 2006) which has shown the benefits of using Glass ("Returnable bottle") vs. other packaging alternatives, as shown in Figure 10:

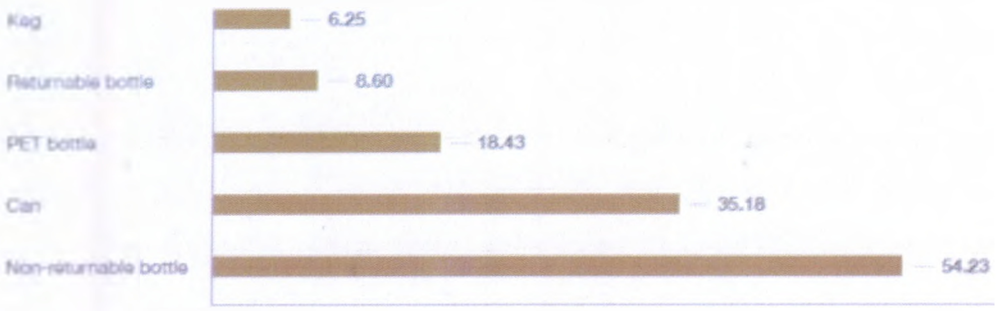


Figure 10: "Average greenhouse gas emissions by packaging type (kgCO2e/hl per SKU)" (SABMiller, 2015)

(Pasqualino, et al., 2011) have concluded that packaging process of a plastic container of water and juice has the highest environmental impact amongst all the activities that take place during the life cycle of the container. Another study by (Humbert, et al., 2009) has established that plastic packaging for baby food is slightly better over its Glass alternative.

(Heineken, 2013) identified that thermal and electrical energy is required for the production of the company's beverages, which are mainly in non-returnable glass containers. Thermal energy is defined as energy that comes from fuel used on site for heat generation, while electrical energy refers to the electricity consumption required on site. Thermal energy is measured in MJ/hl and electrical energy in kWh/hl. The business has quantified that the majority of this energy is consumed in the beverage production and packaging process on site. As part of environmental conservation programs the (Heineken, 2013) has identified that thermal energy is best reduced by new, more thermally efficient equipment and improved recycling projects while electrical energy is best reduced by switching to a renewable source of electricity generation. Furthermore, (Heineken, 2013) defines the measurement for greenhouse gas emissions i.e. kgCO$_2$e/hl.

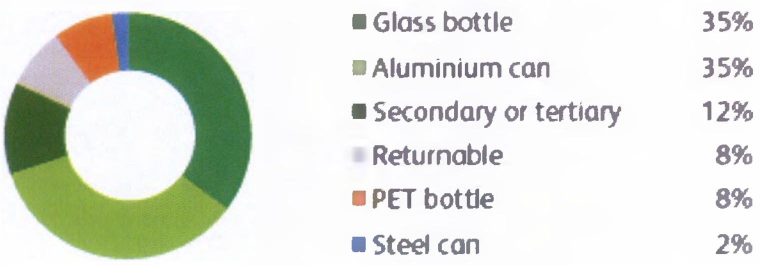


Figure 11: Contribution of different packaging containers to total packaging emissions (Heineken, 2013)

It must be noted that Glass packaging process emissions are higher than PET in the figure above, as it is the main primary packaging material for the business and majority of business products are packaged in this type of container. Also the main focus of the study was on reducing the physical weight of the containers as well as developing more efficient recycling initiatives. (Heineken, 2013) The energy used on the packaging lines has been seldom found to be at the forefront of such improvement programs and as such it requires investigation.

Figure 12 is an excerpt from an LCA study adhering to (ISO 14040/14044, 2006) and conducted by (Ghosh & Socci, 2012) on the Pepsi Co. Although the study has focused on evaluating the cradle to grave LCA of the different packaging containers the company uses for its products, it did not cover the Filling (packaging process) energy associated with the various containers.

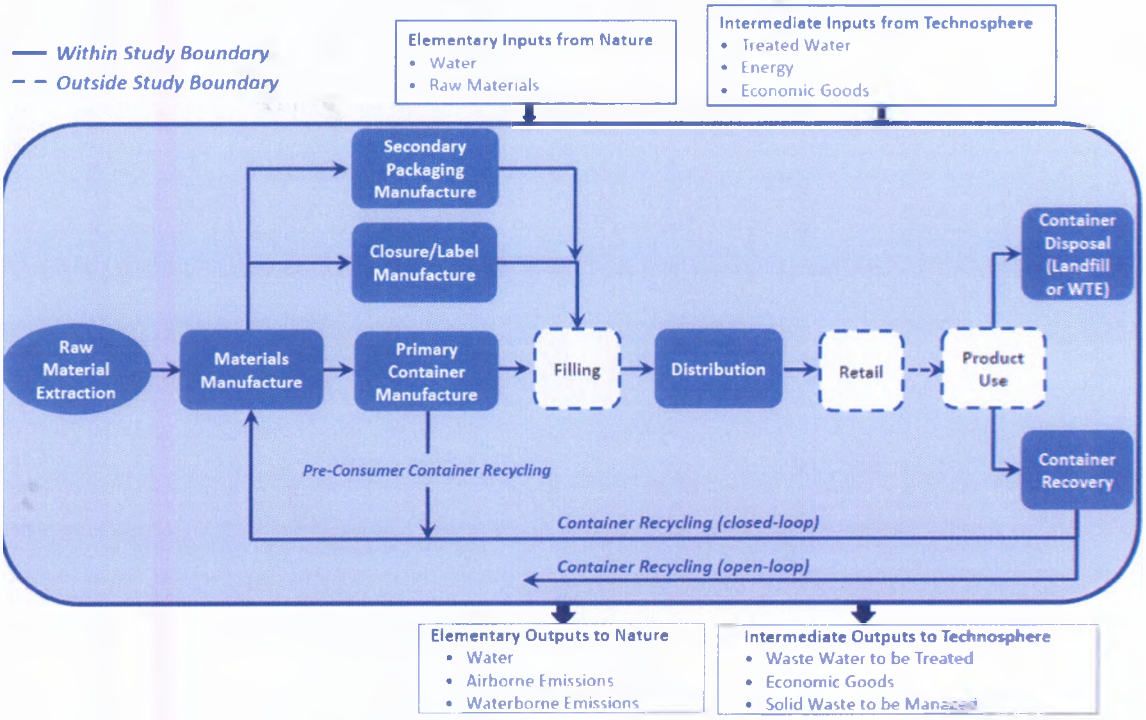


Figure 12: System boundaries for a LCA for the PepsiCo (Ghosh & Socci, 2012)

With reference to another excerpt from (Ghosh & Socci, 2012), it is interesting to point out that in terms of GHG emissions and total energy demand i.e. CED overall, excluding the manufacturing part of the process, Glass results in 1.6 times more GHG emissions than PET and Glass requires 1.2 times the CED than PET.

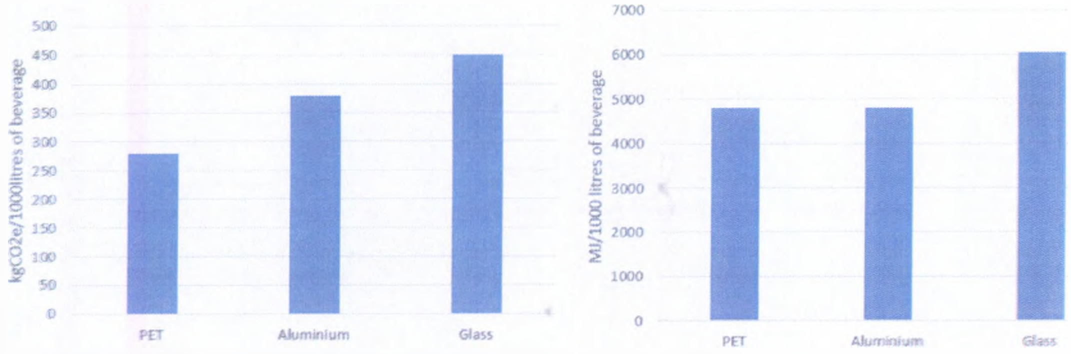


Figure 13: PepsiCo results comparison (Ghosh & Socci, 2012)

Hence the packaging process life cycle stage has not been considered, it would be of academic importance to investigate how the integration of GHG and CED of the manufacturing (CSD packaging) process will affect PET and Glass containers' GWP.

2.3 Selecting gaps for the research

In summary, from all the studies which relate to conducting an LCA on different beverage packaging options such as (Vellini & Savioli, 2009), (Gleick & Cooley, 2009), (Pasqualino, et al., 2011), few e.g. (Journey Staff - Coca-Cola, 2010) and (Doublet, 2012), directly investigate the carbon footprint of packaging CSDs in Glass and PET containers alone. As far as the research for this project has gone there has been no evidence found for work done on the carbon footprint of the CSD packaging process for PET and Glass containers in South Africa. Therefore any work conducted hereby will be the first of its kind.

Different LCA studies have different results regarding the contribution impact for each life cycle stage for Glass and PET. Some studies (e.g. (Amienyo, et al., 2013)) suggest that the packaging process life stage is insignificant to the total environmental cost of the products while others (e.g. (Pasqualino, et al., 2011)) identify it as the life stage with most significant environmental impact. Furthermore, no conclusive evidence exists in favour of either of the two materials i.e. the environmental cost for the CSD packaging process in Glass and PET containers is not definitive. Hence a targeted case study, which will provide a repeatable method for quantification of PCF, for the soft drinks manufacturer under investigation, will be beneficial in closing this gap in literature as well as providing the business under investigation with valuable information about their products, which stakeholders can use in preparation for the potential carbon tax legislation in South Africa.

Furthermore, no conclusive evidence exists which supports the packaging process dominance, in terms of GHGs emissions, of Glass over PET. Therefore, this creates the need for this current study which would be used by the business to determine how their operations impact on its potential future carbon tax.

In majority of the literature found (Doublet, 2012), (Pasqualino, et al., 2011), (Franklin Associates, 2009), (Flanigan, et al., 2013) (Ganji, et al., 2002), etc. the life cycle analysis uses data from (Ecoinvent, 2015). This is a theoretical database and it deviates from business specific data. This is a gap in literature that will be closed with this research as the study will collect and use real business data as much as possible for its analysis.

LCA studies (e.g. (Amienyo, et al., 2013), (Flanigan, et al., 2013), (Pasqualino, et al., 2011) etc.) have been found to be time and resource consuming. Although the significance of conducting a full blown LCA for the business is vast, for the purposes of the current business needs identified by this research, such an analysis is not required at this time and has to be conducted as future work.

In summary, the following literature gaps are identified:

- No research on PCF for CSD packaging process done in South Africa
- PCF research depends on many external factors such as technical, geographical and operational and the results of one study in one country cannot be directly translated to a business in another country
- No clear conclusion on the most expensive environmental life stage for Glass and PET containers
- No clear conclusion on which material (Glass or PET) has a lower environmental impact
- Studies on the packaging process of Glass and PET either use theoretical data from databases or they do not include all the steps of the process into consideration when calculating the environmental impact
- Literature available (e.g. Journal of Life Cycle Assessment) mostly focuses on the production and recycling of PET and Glass and does not offer any insight into how the usage of these materials in the CSD packaging process affects the consumption of non-renewable resources

In summary, the research project is expected to have the following benefits:

- Environmental awareness regarding the packaging of CSD in PET and Glass containers in South Africa
- Assistance to the business under investigation to better plan its future initiatives, in the context of South Africa's potential new carbon tax regulation, by providing insightful energy quantifications with respect to packaging container choice across its SKU portfolio. This will also positively impact the business' corporate governance
- Provide a method which can be applied by a different manufacturing businesses to better understand their role in reducing South Africa's carbon footprint
- Providing literature with a generic calculation model that can be used, to assess different PCF for a variety of similar processes
- Create opportunities for further academic research by providing recommendation which build on the existing study

3. Problem Statement, research questions and objectives

The problem statement for this research project is defined as follows:

Quantify the environmental impact in terms of Global Warming Potential for the CSD packaging process of returnable glass and PET containers for a South African business in Gauteng in light of the potential new carbon tax legislation. Hence, determine which type of packaging process has a lower carbon footprint.

The main focus of the research is to quantify the Cumulative energy demand (CED) of PET and Glass containers during their respective packaging processes. The Greenhouse Gas emissions will be calculated based on the nature of the sources of this CED and hence the carbon footprint on the environment determined as measured by GWP. Furthermore, using less energy does not necessarily mean that a certain process is greener than another. This paradox emerges in the realisation that processes that use renewable resources of power have less of an overall impact on the environment than those derived from non-renewables. This means that a process that is more energy intensive may still have an overall lower footprint. For example one process can use 100kWh and another 150kWh, however upon breaking these two processes down to the usage of non-renewable resources one can find that the 150kJ process consists of 50kJ which are generated from non-renewable resources, while the 100kJ consists of 100kJ directly generated from non-renewable resources. Hence, the following research questions were developed to provide more insight into the packaging "greenness" of PET and Glass containers:

Research question 1:

Given two similar sized containers (Glass and PET), which of the two have a lower Cumulative Energy Demand (CED) during their respective (CSD) packaging process?

Research question 2:

What sources of energy are used i.e. the CED breakdown each of the two (Glass and PET) CSD packaging processes?

Research question 3:

What are the Greenhouse Gases (GHGs) emitted by each source of energy in terms of weight of CO_2e and hence which packaging process has a lower Global Warming Potential (GWP)?

Research question 4:

Which CSD packaging process (Glass or PET) is associated with a lower carbon tax for the business?

Hence the following objectives are developed for the project:

- Quantify the energy requirement of all unit processes, main utilities and raw materials required for the packaging process of a PET and a Glass container on a carbonated soft drinks' packaging line operating within a South African business in Gauteng in order to determine the respective process' CED
- Determine which container uses the least amount of energy during its respective packaging process in terms of CED
- Determine the breakdown of direct and indirect CED in terms of source of energy used by each of the unit blocks for the packaging process of Glass and PET e.g. how much of the CED for the packaging process of a PET and a Glass container can be directly attributed to fossil fuels i.e. purchased electricity
- Quantify the GHGs in terms of weight of CO_2e as a result of the packaging process, main utilities and raw packaging materials for Glass and PET to determine which type of packaging process is associated with a lower overall GWP and hence results in a lower carbon taxation to the business
- Understand the impact on CED and GWP when using Glass and PET containers of different size
- Provide recommendations on the usage of the two types of containers as a packaging choice for the selected South African business in terms of their environmental impact and carbon tax

4. Study approach, Scope, Limitations and Assumptions

4.1 Study approach

Two types of approach can be adopted to address the research problem statement and objectives:

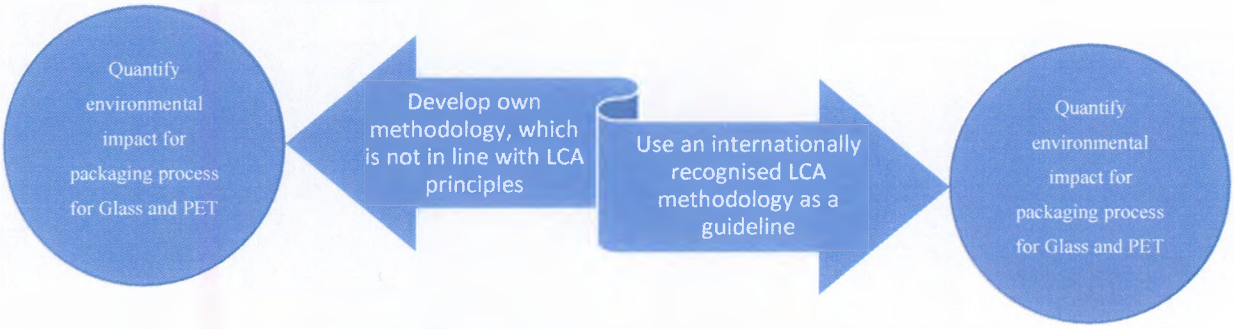


Figure 14: Research study methodology choice

Both of these approaches will be able to address the research questions defined in the previous section. However, using the LCA approach as a guideline far outweighs developing and following an own methodology. Table 5 summarises the criteria used in selecting the appropriate approach for this research:

Table 5: Criteria for selecting a methodology approach

Criteria	**Develop own methodology, not in line with LCA principles**	**Use an internationally recognised LCA methodology as a guideline**
Research integrated in future work such as evaluating the whole life cycle of Glass and PET in the business' supply chain	× (could not be integrated as a full LCA will require a proper LCA method)	✓ (could easily be integrated with a full blown LCA study)
Research credibility and validity. Confidence by the business in the results	× (has not been done before and may miss important investigation areas)	✓ (internationally recognised and used by academics worldwide)
Ability to compare results to existing LCA studies	× (not possible as methodology is different)	✓ (easy to compare as methodology would be consistent with existing literature)
Ability to integrate results into existing LCA studies to better understand impact of PET and Glass	× (not possible as methodology is different)	✓ (easy to compare as methodology would be consistent with existing literature)

Based on the table above, the research methodology approach criteria are best met by using an LCA method as a guideline for conducting this research. It is important to highlight that although an LCA method is used, this is not an LCA study. The LCA method is only applied as a guideline to the packaging process life cycle stage of Glass and PET. Conducting a full blown LCA falls outside of the scope of this study due to its complexity in terms of cost, resources and time required to complete it. Furthermore, as majority of academic research shows (refer to Literature Review Section 2), there's little clarity on the detailed environmental cost for the packaging process of the two types of containers. Hence the research focuses on this present literature uncertainty.

A special case for LCA is Product Carbon Footprint (PCF). PCF focuses on the impact of GHG emissions only (i.e. GWP), as opposed to LCA which can consider many different environmental impacts, and therefore it is better aligned with the goal and scope of this project, because only the GWP is of interest.

(ISO 14040/14044, 2006), (World Resource Institute, 2013) are internationally recognised and accepted standard in the field of LCAs and PCF used by academics worldwide, as shown Section 2. The GHG protocol is selected to be used as a guide for conducting the research. A comparison between the adopted approach and ISO protocols is not done as ISO standards come at cost which is not budgeted for in this research.

The study analyses the core operation of a South African CSD manufacturing business i.e. packaging process in Glass and PET containers only and therefore cannot be categorised as an LCA. However, as discussed above, PCF approach is adopted as a guideline. The figure below shows all major life cycle stages which can be considered when undertaking a LCA for a typical CSD manufacturing business (Flanigan, et al., 2013). The life cycle stage labelled "Packaged goods manufacture" in Figure 15 was investigated, because it contains the packaging process which is focus of this research.

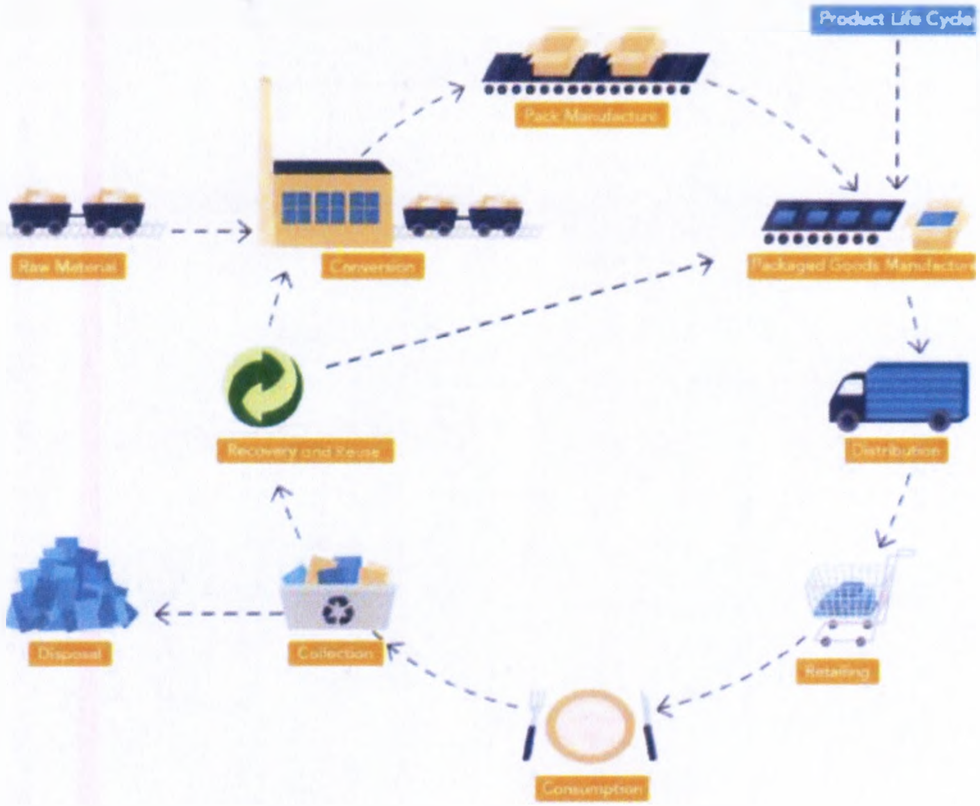


Figure 15: LCA stages for a typical packaging product (Flanigan, et al., 2013)

Figure 15 can be simplified, as shown in the diagram below. For the purposes of this research, only the area highlighted in grey in Figure 16 is studied i.e. CSD packaging process in PET/Glass containers.

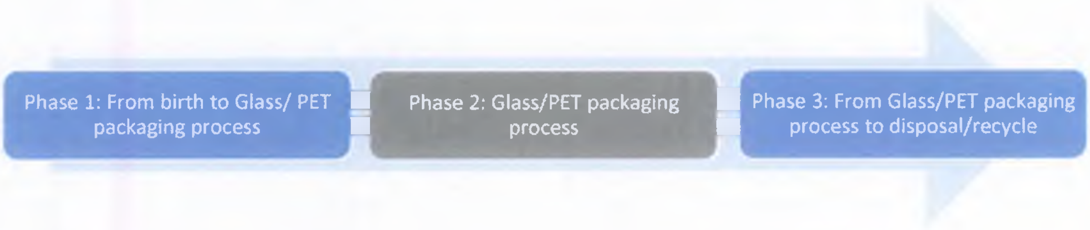


Figure 16: Summarised life cycle stages for Glass and PET from the point of view of the scope for this research

Phase 1: From birth to Glass/ PET packaging process

This phase is outside of the scope for this research and consists of all processes related to acquiring the raw materials, their manufacture and all necessary transportation and storage of PET and Glass containers in order for them to get to their respective CSD packaging line. It must be noted that although the main packaging raw materials form part of this stage they are still considered in the scope of the research in terms of their GWP contribution.

Phase 2: Glass/PET CSD packaging process

This is the life cycle stage considered in this research. The PCF of Glass and PET is for this stage only. It deals with the packaging process of CSD in PET and Glass containers. The starting point is when empty Glass and PET containers enter their respective packaging lines and ends when these containers are filled, sealed, stacked on a pallet and ready to leave their respective packaging lines e.g. a pallet at the exit conveyor of a palletiser ready to be collected by a Forklift (FLT) to be allocated to the finished goods' warehouse floor.

Phase 3: From Glass/PET CSD packaging process to disposal/recycle

This phase is outside of the scope for this research and consists of all the processes related to storage and transportation of the packaged CSD Glass and PET containers from the time they leave their respective packaging line to the time of their disposal/recycle.

4.1.1 The product systems and functions

The product system is defined as the CSD PET and Glass packaging lines, which house the packaging process. The function of the packaging line is to package (unpack, prepare for filling, fill, seal, label and pack) CSD in Glass and PET containers by using a combination of highly automated machinery. Glass packaging lines are different to PET packaging lines as they have different process units.

4.1.2 Functional unit

Hectolitre (hl) is the volumetric functional unit selected for the study i.e. the study assesses the environmental impact in terms of the GWP for the Glass and PET packaging process per hl of CSD.

4.1.3 Product system boundaries

The packaging process on the Glass and PET packaging lines of the CSD manufacturing business is the core operation of the business selected to be studied. Anything outside of the packaging lines will not be considered, except GWP of the main packaging raw materials. The packaging line starts when the empty Glass or PET container arrives at the line and ends when the filled and sealed Glass or PET container leaves the packaging line. Energy inputs to the unit processes will be traced back to energy point of origin in order to assess the environmental impact of the packaging process as measured by GWP requirements.

4.1.4 Allocation procedures, types of impact and methodology of impact assessment

(World Resource Institute, 2013) is the internationally used guideline to identify and quantify the GHG emissions for the CSD packaging process in Glass and PET. Indirect and direct GHG emissions (expressed in tonnes of CO_2e) are considered for impact assessment. The method for this impact assessment is as follows: (World Resource Institute, 2013)

1. Categorise the GHG emissions within the CSD packaging process for Glass and PET. This will be done by mapping the elementary input of unit process which together form the product system i.e. packaging line
    a. Stationary combustion – combustion of fuels in stationary equipment such as boilers on site
    b. Mobile combustion (emissions due to mobile equipment used by the company) – outside of the scope for this study, as explained in section 6.1.7
    c. Process emissions – direct emissions generated by the unit processes of the packaging process for Glass and PET
    d. Fugitive emissions – intentional and unintentional emissions by equipment such as compressors and boilers
2. Calculation approach – the technical, machine and factory specific, design specifications of the unit processes are used to determine the theoretical input and output of material and energy. Actual (metered) energy consumption was not used. Documented emission factors and fuel use data are then used to obtain the carbon content coefficients and hence calculate the GHG emissions of unit processes in the packaging process for Glass and PET. Calculation tools provided by the (World Resource Institute, 2013) are used as guidance and a generic calculation tool is developed in MS Excel to obtain results

4.1.5 Data requirements

The main data requirements used by this research are presented below. Appendix B contains a more comprehensive description of data implications usually considered when undertaking a PCF study.

4.1.5.1 Time, geographical and technical coverage

The latest, region specific factors such as type of coal used for energy generation, country of origin and method of combustion as provided by (World Resource Institute, 2013) are used for the study

4.1.5.2 Precision, completeness and representativeness of the data

Internationally recognised principles are adopted as a guideline for this research from (World Resource Institute, 2013). The GHG emissions for the company are calculated using these standards. All emission sources and activities and processes within the Glass and PET packaging processes' boundary, which are relevant to the research questions, are captured to ensure completeness. Transparency is ensured by addressing all relevant issues as well as disclosing all assumptions and references used in this research. Thus it is ensured that the calculated emissions are reflected on appropriately and the results will satisfy the decision making needs of the business.

4.1.5.3 Consistency and reproducibility of the methods for the PCF

The calculation procedures for determining the environmental impact of the packaging process for Glass are the same for the packaging process for PET. Data is collected using the same method and from the same sources to ensure consistency of results. An MS Excel spread sheet is developed for the calculation of the GHG emissions for the packaging process of Glass and PET. The model construction and assumptions are clearly defined in this report such that the business as well as academics may use it in the future to re-calculate new GHG emissions in case of operational and/or technology improvements/changes and to conduct further research.

4.1.5.4 Data sources

Data on CO_2e conversion factors is from credible sources such as (World Resource Institute, 2013). This data represents the latest and up to date numbers of GHG emissions. Furthermore, data is obtained from specific sites, published sources and from the business production facilities in Gauteng. The material and energy inputs to the unit processes are be obtained from the technical specifications of the unit processes' OEM manuals. The energy requirement calculation takes into account the different sources of energy used as well as the efficiency of conversion and distribution of the energy flow. (ISO 14040, 2006)

4.1.5.5 Uncertainty of the information

Theoretical emission factors as provided by the (World Resource Institute, 2013) are used over facility-specific emission factors (lack of such locally available factors). Theoretical technical specifications of the unit processes of the packaging process for Glass and PET as provided by the OEM manuals are used, which in reality may deviate from the actual values due to machine degradation or modifications. After discussions with technical staff on site, it was assumed that such deviations are minimal and that unit processes operate as per their specifications and hence assumed to be the true consumption from the grid. This was done by measuring some of the unit processes current drawn with a clamp ammeter. When site specific data is available, (World Resource Institute, 2013) advises that an uncertainty analysis is not appropriate. Hence for the most part the data collected for the study is site specific, an uncertainty analysis was not done.

4.1.6 Assumptions of the research

The study has the following assumptions. Some of the information is obtained from the business, but there's no direct reference due to ethics reasons:

- Environmental impact due to material inputs into the packaging process such as Glass, PET, closures, labels etc. will be obtained from published sources. These sources are assumed to provide up to date, credible information, because of their use in other similar LCA studies
- The return rate of Glass and HDPE plastic crates is assumed to be 97%, as provided by the company
- The business would not change its sales profile i.e. PET and Glass containers sales will remain the same in the near future. Hence, the business will find the information provided by this research useful when developing its strategic plan
- As shown in the literature review, LCAs conducted for glass and PET show that there's no clear winner between the two in terms of overall environmental impact. The way PET and Glass containers are manufactured in South Africa will not change in the near future and hence only company specific changes in the handling of the two types of containers in the CSD manufacturing process of the South African business will result in "green" improvements
- Temporary technical faults, which cause more energy to be consumed by a unit process/s on the Glass and PET packaging lines, are not taken into account. It is assumed that these are short term and fixed by the business in due time
- All of the components on the packaging lines are operating as per their OEM specifications
- The direct GHG emissions from the coal boilers required for steam generation for the Glass packaging process are calculated using theoretical GHG emissions which would occur when burning a 1kg of coal in a power station

- When calculating the raw materials GWP it is assumed that the relationship between weight of the raw material and the corresponding GWP value is directly proportional, as provided by literature
- 500ml PET container is the closest in comparison to a 300ml Glass container in terms of the packaging lines' sizes and their components. The other possible comparison of 1000ml PET and 1250ml Glass has a greater volumetric difference (250ml) than the selected option (200ml) and hence is not selected for this research
- The losses made on the packaging lines are assumed to require the same amount of effort to remove from the packaging lines, as provided by the business, and therefore are not considered in the energy quantifications i.e. removal of waste from the packaging lines is not taken into account
- The PET and glass containers considered are assumed to be best in class, which means that there are no extra considerations with respect to energy quantifications that may result as an effect from using a poor quality container
- The principal greenhouse gas emission associated with the production of purchased electricity is CO_2 (World Resource Institute, 2013) and hence it is the only gas considered in the calculation of GHG emissions for purchased electricity
- Unit processes run at rated speeds during normal production on both Glass and PET packaging lines, as verified by company technical staff
- Overheads are assumed to be the same for the Glass and PET CSD packaging lines
- Coal is used as the main purchased electricity fuel, because it is the main source of energy generation in South Africa and because the business is assumed to get all of its power from a coal-burning power station. Furthermore it is assumed that coal burners, whether on site or in a boiler on site have similar performance i.e. it is assumed that they operate at the same efficiencies and that the emissions from burning the same type of coal in both would be the same (International Energy Agency, 2010)
- Container size is dictated by marketing constraints and hence the business is not allowed to change the volumetric sizes of its PET and Glass containers
- The same unit processes on the Glass and PET packaging lines can run the different SKU pack sizes with the required modification i.e. the same filler which fills 500ml PET bottles, drawing the same power, but running at a slower speed would be able to fill 2000ml PET

- The fugitive emissions associated with the 7 bar pressurised air, chilled and chlorinated water are similar for both CSD packaging processes in Glass and PET containers and hence are excluded from the analysis

4.1.7 Limitations of the research

The limitations of the research follow below:

- Phases 1 and 3 as depicted by Figure 17 are not considered, with the exception of main packaging raw materials
- Overhead energy consumptions such as packaging lines offices and lighting are not considered in this research, because it is assumed that these are identical for both Glass and PET packaging lines i.e. a Glass packaging line can be replaced by a PET line and its overheads will stay the same
- The impact on the environment due to the construction of the packaging line building is not considered
- The project uses PCF principles as defined by the (World Resource Institute, 2013) as a guideline only due to cost, resources and time constraints
- Secondary packaging materials which are added to the PET/Glass containers and the energy required to get them to the packaging line (e.g. CSD ingredients) are not considered in this research. Only PCF of the main secondary packaging raw material (bottle caps/crowns, shrink wrap, pallets, crates, labels and pallet wrap) in CO_2e as obtained from published sources is taken into account
- All Glass and PET functional system commonalities such as quality assurance stations are excluded from the study
- The results of the study cannot be generalised to other businesses because each business will have its own specific equipment as well as its own operational practices. The results will only apply to the South African company in Gauteng selected for this research. Nevertheless, other companies can use the research to get a general understanding of CSD PCF. Due to its transparent nature the method can be used by academics to conduct comparison studies in other businesses
- The impact of the ramp up process during production is not taken into account. Only steady running state of unit processes is considered
- The energy used to supply unit processes with inputs to the packaging process in not taken into account. For example, the energy to transport water to the blow moulder is

not considered in the calculations as it is assumed that it is a closed system with minimal energy requirements

- The energy and carbon footprint required to manufacture, transport, install and commission the unit processes to the manufacturing site in not taken into account
- The focus of the study is the direct energy consumed by machines forming part of the packaging lines for PET and Glass. Only main energy consumers such as main utilities (e.g. compressors) are taken into account
- The emission factors used for purchased electricity are obtained from (World Resource Institute, 2013) and factors such as power station efficiency and power transmission distances from the power station to the business under investigation are not taken into account
- The peak power consumption and its effect on the business carbon tax is not in the scope of this study
- When conducting the dynamic model analysis only the unit processes' CED and GWP are compared, because obtaining all the details associated with the overall packaging process for 2000ml PET and 1250ml Glass is outside of the scope for the study
- The impact on the environment is only considered in terms of global warming potential (GWP) which is measured in CO_2e and which can directly be related to carbon tax. Other impacts such as:
    - (ADP) - Abiotic depletion
    - (AP) - Acidification
    - (HTP) – Human toxicity
    - (FAETP) – Fresh water toxicity
    - (MAETP) – Marine water toxicity
    - (POCP) – Photochemical oxidant creation
    - (EP) – Eutrophication
    - (TETP) – Terrestrial Eco toxicity
    - (ODP) – Ozone depletion
    - (POCP) – Photochemical oxidant creation

have not been measured

4.1.8 Critical review

A critical review will not be conducted for this research. The author of this report has taken the responsibility to ensure that the key principles and guidelines from (World Resource Institute, 2013) are adhered to when conducting the work.

5. Research Method

The method undertaken for this research is as follows:

a. Setting the context

i. Research to understand the relationship between CED and GWP
   a. Identify how CED for a certain process is measured i.e. what needs to be considered when calculating the CED for a given product/service
   b. Identify how CED relates to GHG emissions i.e. allocate GHG emissions to the CED required for a given product/service
   c. Identify the relationship between GHG emissions and GWP i.e. how are the different GHGs expressed in terms of CO_2e

b. Sample section

ii. Select a CSD manufacturing business in South Africa and identify two packaging lines within the business, which package similar sized PET and Glass containers (one packaging line for PET and one packaging line for Glass). Compare the volumetric difference between the different Glass and PET containers and select the combination with the lowest difference

iii. Process map the respective packaging lines (functional systems) (PET and returnable glass) to identify all key unit processes (e.g. blow moulders, storage silo, conveyors, labeller, filler, etc. on the PET packaging line and bottle washer, conveyors, filler, etc. on the Glass packaging line). Key unit processes are directly involved in the packaging process for CSD in Glass and PET containers. These are identified from packaging line layouts and direct observations of the product system. All unit processes are expressed separately (e.g. the two blow moulders on the PET packaging line are not combined) to ensure that individual contributions can be identified and analysed

iv. Identify and list all main packaging raw materials (e.g. plastic crates, shrink wrap, etc.) and utilities (e.g. steam, compressors) and map the connections between the main packaging raw materials and utilities and all the identified unit processes for the Glass and PET packaging lines

c. Data collection and model construction

v. Collect technical specifications for all the key unit processes for the Glass and PET packaging lines such as operating speed per hour and power consumption from business owned OEM manuals. Use the help of the electrical technician for the respective packaging line to make sure that the correct information is obtained in full. Understand the source of the energy consumed

vi. Consult the businesses' utilities department to understand what the main utilities are and in what quantities they are delivered to the unit processes. Determine the energy source powering up these utilities
vii. Consult the business' bill of materials to accurately determine the quantities of main packaging raw materials used per the finished (fully packaged) PET and Glass container
viii. Triangulate the data by consulting with key business personnel on the operation of the packaging lines to verify all unit process maps. Gather outstanding data from the business
ix. Construct an MS Excel model, which incorporates relevant data collected in the steps above, as well as information form published sources such as (World Resource Institute, 2013) calculation tools to calculate the CED (kWh/hl) and GWP (gCO_2e) for the CSD packaging process in PET and Glass containers

a. <u>Model inputs</u>

A MS Excel calculation model is developed as part of the study to calculate the CED used by the Glass and PET CSD packaging processes as well as their respective GHG emissions. Analysis (for PET and Glass containers of different size) can be done by changing the inputs of the model and quantify how CED and GWP will change. This is one of the main reasons for building a dynamic model and not simply a table that sums the individual unit process contributions for the respective CSD packaging process.

The inputs for the model are:

i. Glass and PET packaging container size (hl)
ii. Power consumption of Glass and PET CSD packaging processes' unit processes (kW)
iii. Operating speed of Glass and PET CSD packaging processes' unit processes during normal production (bph)
iv. Consumption (kWh) of main utilities per hl, as supplied by the business
v. Weight (grams) of main raw packaging materials for the finished (fully packaged) Glass and PET container
vi. Conversion factors for the relationship between weight of coal and power generation, obtained from the business

vii. GHG emissions for the main packaging raw materials, obtained from literature (Amienyo, et al., 2013)

viii. GHG emission factors for purchased electricity for Glass and PET. Emission factors are obtained from a calculation spread sheet as provided by the (World Resource Institute, 2013), see Appendix D

b. Model development

The calculation logic used by the model to calculate the CED for the CSD PET and Glass packaging processes' unit processes is shown in Figure 17:

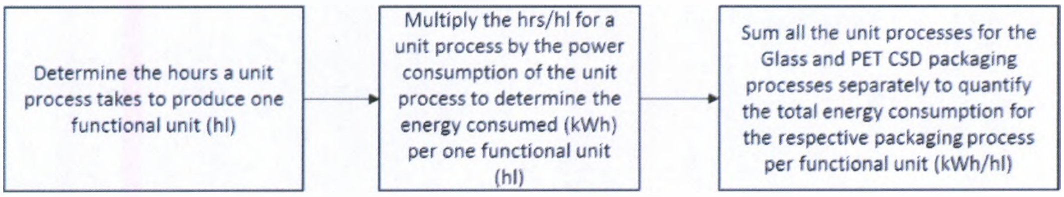


Figure 17: CED per functional unit calculation logic

The calculation logic for quantifying the GHG emissions and in consequence the GWP for the CSD Glass and PET packaging processes' main packaging raw materials in the model is based on quantification principles as specified by (World Resource Institute, 2013). The process flow diagram in Figure 18 depicts this logic.

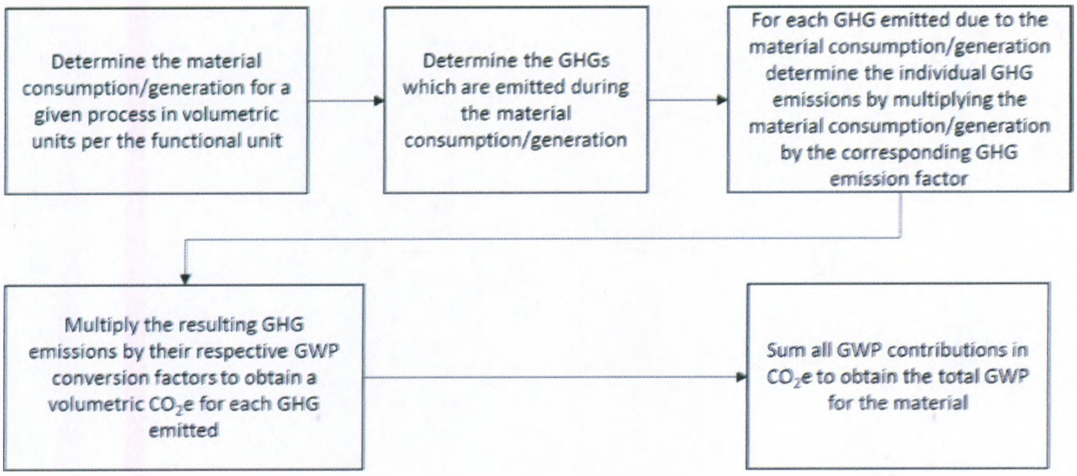


Figure 18: Model GHG emissions in CO2e calculation logic process flow

The equations for the calculations in the figure above are:

1. GHG emission/functional unit (t/hl) = material consumption/generation (m^3/hl) X Corresponding GHG emission factor (t/m^3)
2. Total GWP per functional unit (tCO_2e/hl) = Σ [GHG emission/functional unit (t/hl) X GWP factor for GHG (CO_2e)]

Key:

t – Tonne

m^3 – cubic meters

hl - hectolitre

The GWP due to purchased electricity is calculated using the following logic.

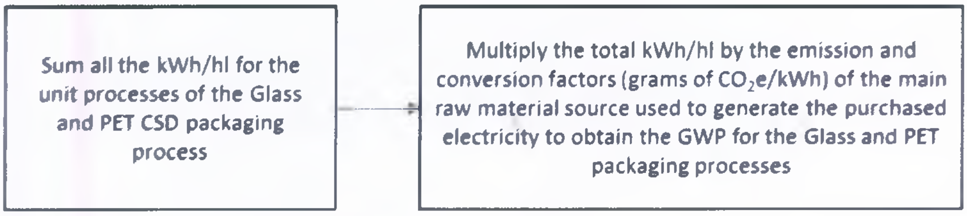


Figure 19: Purchased electricity GWP calculation logic

A copy of the MS Excel model is available in digital format in Appendix C.

c. Model validation

To determine the validity of the model an example is used (Shailesh, 2012). The model is run with the inputs from the example first. The results of the model are then compared to the results of the example. The model's calculation logic is validated when these two results are the same.

The model is also validated by cross checking a critical output (hr/hl) by using the logic described in the process diagram Figure 20.

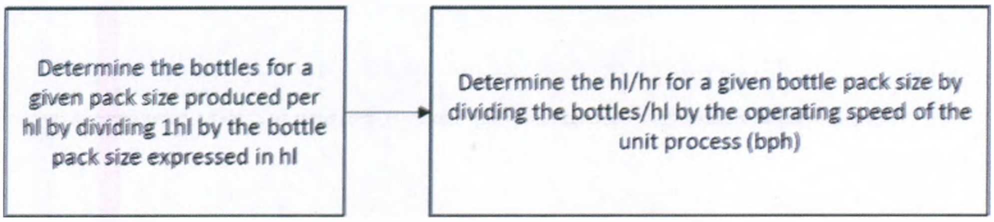


Figure 20: Calculation logic for cross checking hl/hr

When the results match, the model is considered to be validated. It is important to note that the model is not a complex one and hence does not require further extensive cross checking and validation.

d. Model outputs

Table 6 summarises the type of results obtained from the MS Excel calculation model.

Table 6: MS Excel model summary of outputs

Type of container	**CSD Packaging process' unit processes and main utilities CED (kWh/hl)**	**CSD Packaging process' unit processes, main raw packaging materials and utilities GWP (CO_2e)**
300ml Glass	✓	✓
500ml PET	✓	✓

x. Perform a dynamic model analysis by testing Glass and PET containers of different size, which are compatible with the business' existing packaging lines, with the MS Excel model to determine the impact container size has on CED and GWP of the CSD packaging process` unit processes. Inputs such as bottle size and unit processes ratings would be changed

d. Reporting and ethics

xi. Discuss the results to determine the effect of the Glass and PET packaging process on the business' carbon tax
xii. Develop recommendation for the business based on the discussion of the results
xiii. Develop recommendations for new or further academic research
xiv. Do not at any point implicitly and/or explicitly disclose the identity of the business
xv. Do not supply sensitive business information e.g. sales forecast
xvi. Do not explicitly and/or implicitly quote a person employed by the business
xvii. Do not include detailed information, which was provided by the business in the Appendices of the report

xviii. Express the results per functional unit such that the sales of the business remain confidential

xix. Copy the MS Excel model on a CD such that it is electronically available

xx. Provide the business with a copy of the report, upon request

xxi. Return raw documentation obtained from the business back to the business

6. Observations

This section provides an overview of the product systems for the CSD packaging process in 300ml Glass and 500ml PET. This combination of containers has the lowest volumetric difference across all combinations and hence selected for the investigation. The section follows by providing relevant technical information about each unit process. The section concludes by providing GHG emissions information on the main packaging raw material inputs and utilities for the two packaging processes.

6.1 Selecting Glass and PET container size

The selected business manufactures CSD in PET and Glass containers in the sizes listed in Table 7:

Table 7: Selecting PET and Glass containers for comparison

Volumetric unit	PET	Glass	Difference
ml	500	300	200
ml	1000	1250	250
ml	2000	N/A	N/A
ml	2250	N/A	N/A
ml	2500	N/A	N/A

The smallest volumetric difference of 200ml is between the 500ml PET and 300ml RGB containers and therefore these two variations are selected for comparison. One packaging line that makes the 500ml PET and one packaging line that makes the 300ml RGB are then selected.

6.2 500ml PET product system's unit processes

Figure 21 is a schematic representation of the unit processes of the 500ml CSD PET packaging line. The blue blocks and arrows represent the unit processes considered. The yellow block and arrow are excluded. These two unit processes represent the CSD assembly and transportation to the filler. They are a common factor between the CSD PET and Glass packaging lines and therefore excluded from the analysis. The dotted line highlights the product system boundary. Unit processes outside this boundary are excluded from the study, as stated in section 6.1.7. The green and red arrows are main input and output for the process respectively.

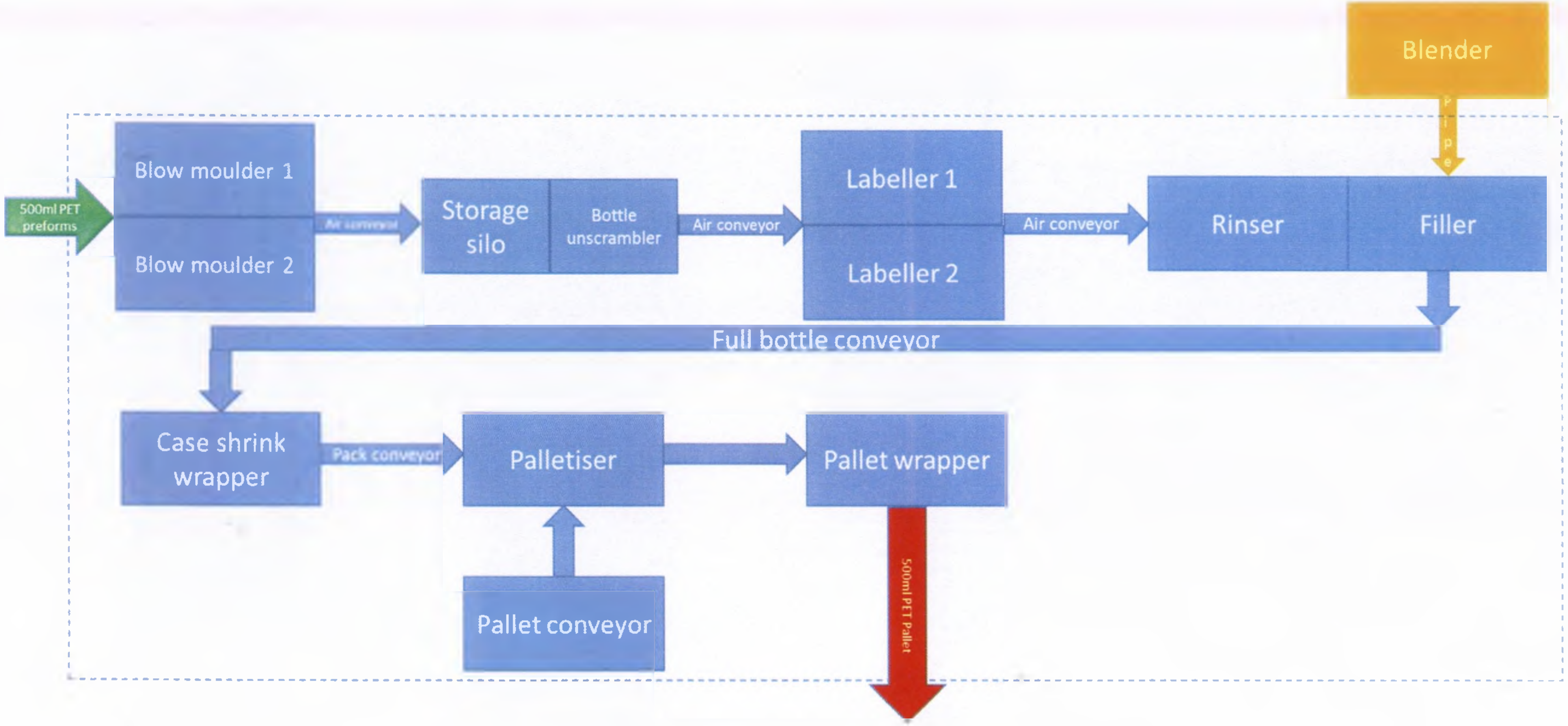


Figure 21: CSD 500ml PET product system's unit processes*

**Only unit processes' names are shown in this diagram as opposed to all their characteristics for readability purposes*

Table 8 up to Table 19 contain all the relevant information regarding the CSD 500ml PET unit processes. Bph – bottles per hour

Table 8: Blow moulder 1 process summary

BLOW MOULDER 1	
Function	To convert PET preforms to blown bottles through a series of heating and blow moulding operations
Operating speed (bph)	18 000
Material input	500ml PET preform
*Power consumption (kW)**	120
Compressed air (bar)	40
Water	8-10°C chilled water via NH3 cooler
Output	Blown 500ml PET bottle

* This is the true consumption from the grid (please see section 4.1.5.5)

Table 9: Blow moulder 2 process summary

BLOW MOULDER 2	
Function	To convert PET preforms to blown bottles through a series of heating and blow moulding operations
Operating speed (bph)	20 400
Material input	500ml PET preform
*Power consumption (kW)**	122.4
Compressed air (bar)	40
Water	8-10°C chilled water via NH3 cooler
Output	Blown 500ml PET bottle

* This is the true consumption from the grid

Table 10: Air conveyors and silo process summary

Air conveyor 1 (blow moulders to silo, silo, silo to labellers, labellers to filler)*	
Function	To transport blown bottles from the blow moulders to the buffer storage silo. To transport bottles from the silo to the labellers and from the labellers to the filler. Operates via electric motors
Operating speed (bph)	40 000
*Power consumption (kW)***	98
Compressed air (bar)	7
Output	Blown 500ml PET bottle

* The motors on these conveyors and storage silo are identical. This table represents the sum of all the motors

** This is the true consumption from the grid

Table 11: Bottle unscrambler process summary

Bottle unscrambler	
Function	To un-scramble blown bottle from the silo and supply them to air conveyor 2
Operating speed (bph)	54 000
*Power consumption (kW)**	4.6
Compressed air (bar)	7
Output	Blown 500ml PET bottle

* This is the true consumption from the grid

Table 12: Labeller 1 process summary

Labeller 1	
Function	To glue a label on a 500ml blown bottle
Operating speed (bph)	40 000
Material input	Blown 500ml PET bottle. Plastic labels
*Power consumption (kW)**	65
Compressed air (bar)	7
Output	Labelled 500ml PET blown bottle

* This is the true consumption from the grid

Table 13: Labeller 2 process summary

Labeller 2	
Function	To glue a label on a 500ml blown bottle
Operating speed (bph)	40 000
Material input	Blown PET bottle, Plastic labels
*Power consumption (kW)**	65
Compressed air (bar)	7
Output	Labelled 500ml PET blown bottle

* This is the true consumption from the grid

Table 14: Rinser and Filler process summary

Rinser and Filler	
Function	To rinse, fill and seal blown and labelled 500ml PET bottles
Operating speed (bph)	40 000
Material input	Blown labelled 500ml PET bottle, plastic cap
*Power consumption (kW)**	38.38
Chlorinated water (ml)	50
Compressed air (bar)	7
Output	Labelled, filled and sealed 500ml PET bottle

* This is the true consumption from the grid

Table 15: Bottle conveyor process summary

Bottle conveyor (filler to case shrink wrapper)	
Function	To transport filled, labelled and sealed 500ml PET bottles from the filler to the case shrink wrapper. Operates via electric motors
Operating speed (bph)	86 400
*Power consumption (kW)**	18.5
Compressed air (bar)	7
Output	Filled, labelled and sealed 500ml PET bottle

* This is the true consumption from the grid

Table 16: Case shrink wrapper process summary

Case shrink wrapper	
Function	To shrink wrap 24 labelled, filled and sealed 500ml PET bottles into a case of 24 bottles
Operating speed (bph)	48 960
Material input	Plastic shrink wrap
*Power consumption (kW)**	215
Compressed air (bar)	7
Output	1 case of 24 labelled, filled and sealed 500ml PET bottles

* This is the true consumption from the grid

Table 17: Pack conveyor process summary

Pack conveyor (case shrink wrapper to palletiser	
Function	To transport a case of 24 shrink wrapped labelled, filled and sealed 500ml PET bottles to the palletiser
Operating speed (bph)	86 400
*Power consumption (kW)**	38
Compressed air (bar)	7
Output	A case of filled, labelled and sealed 500ml PET bottles

* This is the true consumption from the grid

Table 18: Palletiser process summary

Palletiser	
Function	To create a full pallet out of 75 shrink wrap cases of labelled, filled and sealed 500ml PET bottles
Operating speed (bph)	72 000
Material input	Wooden pallets
*Power consumption (kW)**	48.5
Compressed air (bar)	7

Output	1 pallet of 75 shrink wrapped cases of labelled, filled and sealed 500ml PET bottles

* Power for the palletiser and the pallet conveyor and reflects true consumption from the grid

Table 19: Pallet wrapper process summary

Pallet stretch wrapper	
Function	To stretch wrap a full pallet of 75 shrink wrapped cases each with 24 labelled, filled and sealed 500ml PET bottles
Operating speed (bph)	196 360
Material input	Plastic stretch wrap
*Power consumption (kW)**	12
Compressed air (bar)	7
Output	1 stretch wrapped pallet of 75 shrink wrapped cases of labelled, filled and sealed 500ml PET bottles

* This is the true consumption from the grid

6.3 300ml RGB product system's unit processes

Figure 22 is a schematic representation of the unit processes of the 300ml CSD RGB packaging line. The blue blocks and arrows represent the unit processes considered. The yellow block and arrow are excluded. These two unit processes represent the CSD assembly and transportation to the filler. They are a common factor between the CSD PET and Glass packaging lines and therefore excluded from the analysis. The dotted line highlights the product system boundary. Unit processes outside this boundary are excluded from the study, as stated in section 6.1.7. The green and red arrows are main input and output for the process respectively.

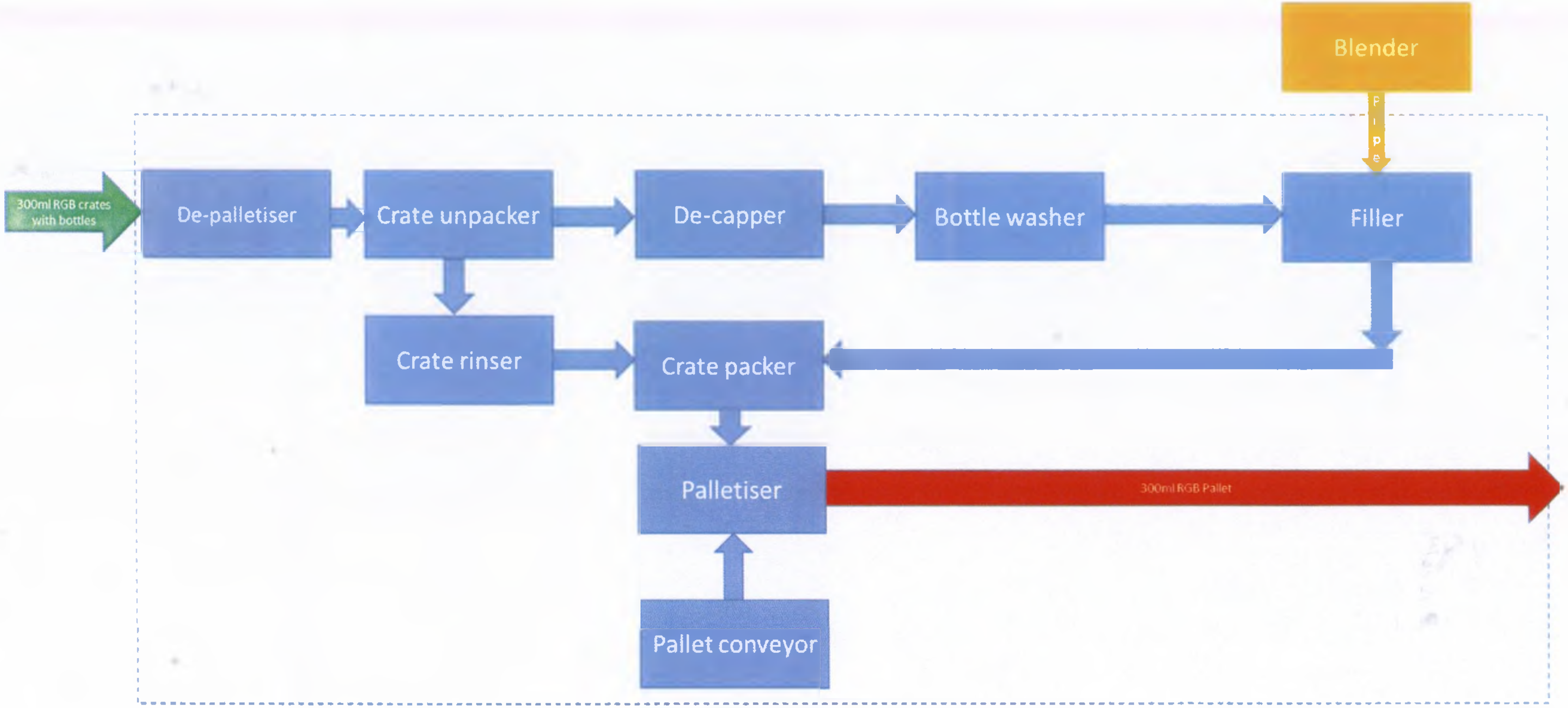


*Figure 22: CSD 300ml RGB product system's unit processes**

**Only unit processes' names are shown in this diagram as opposed to all their characteristics for readability purposes*

Table 20 until Table 28 contain all the relevant information regarding the 300ml RGB unit processes.

Table 20: De-palletiser process summary

De-palletiser	
Function	To break down a pallet of 60x300ml RGB plastic crates into crates with empty bottles
Operating speed (bph)	53 700
Material input	Pallet of 300ml RGB plastic crates with empty 300ml RGB bottles
*Power consumption (kW)**	27.74
Compressed air (bar)	7
Output	300ml RGB plastic crate with 24 empty 300ml RGB bottles

* Includes the pallet conveyor power consumption and is the true consumption from the grid

Table 21: Crate unpacker process summary

Crate unpacker	
Function	To take out the empty 300ml RGB bottles out of the 300ml RGB plastic crate
Operating speed (bph)	45 000
Material input	300ml RGB plastic crate with 300ml empty RGB bottles
*Power consumption (kW)**	15.00
Compressed air (bar)	7
Output	Empty 300ml RGB Plastic crate and 24 empty 300ml RGB bottles

* This is the true consumption from the grid

Table 22: Crate rinser process summary

Crate rinser	
Function	To rinse empty 300ml RGB plastic crates
Operating speed (bph)	45 000
Material input	Empty 300ml RGB plastic crates
*Power consumption (kW)**	5.00
Compressed air (bar)	7
Output	Washed 300ml RGB plastic crate

* This is the true consumption from the grid

Table 23: De-capper process summary*

De-capper	
Function	To remove any loose crowns from the 300ml empty RGB bottles
Operating speed (bph)	N/A
Material input	300ml RGB bottles with loose aluminium crowns
Power consumption (kW)	N/A
Compressed air (bar)	N/A
Output	300ml RGB empty bottle, no aluminium crowns

* This is a mechanical device which removes the crowns as the empty bottles pass through it. The carbon footprint of this device is negligible and is therefore omitted from the scope

Table 24: Bottle washer process summary

Bottle washer	
Function	To sanitise empty 300ml RGB bottles
Operating speed (bph)	42 000
Material input	Empty 300ml RGB bottles
*Power consumption (kW)**	15.2
Compressed air (bar)	7
Steam consumption (tons/hr)	1
Output	Sanitised empty 300ml RGB bottle

* This is the true consumption from the grid

Table 25: Filler process summary

Filler	
Function	To fill and seal empty 300ml RGB bottles with CSD
Operating speed (bph)	36 000
Material input	Empty 300ml RGB bottles and aluminium crowns
*Power consumption (kW)**	7.60
Compressed air (bar)	7
Output	Filled and sealed 300ml RGB bottle

* This is the true consumption from the grid

Table 26: Crate packer process summary

Crate packer	
Function	To pack 24 filled and sealed 300ml RGB bottles into washed 300ml RGB plastic crates
Operating speed (bph)	40 000
Material input	Washed, empty 300ml RGB crates and filled and sealed 300ml RGB bottles
*Power consumption (kW)**	15.00
Compressed air (bar)	7
Output	300ml RGB plastic crate with 24 filled and sealed 300ml RGB bottles

* This is the true consumption from the grid

Table 27: Crate packer process summary

Palletiser	
Function	To stack 60 crates of 300ml RGB plastic crates with 24 300ml RGB filled and sealed bottles onto a pallet
Operating speed (bph)	47 000
Material input	Filled and sealed 300ml RGB bottles into 300ml RGB plastic crates, wooden pallets
*Power consumption (kW)**	36.48
Compressed air (bar)	7
Output	A pallet of 60 crates of 300ml RGB plastic crates with 24 300ml RGB filled and sealed bottles

* Includes crate conveyor power consumption and is the true consumption from the grid

Table 28: Bottle conveyors process summary

Bottle conveyors*	
Function	Transport empty and filled 300ml RGB bottles and empty and filled 300ml RGB plastic crates around the packaging line
Operating speed (bph)	40 000
Material input	Empty and filled 300ml RGB bottles and empty and filled 300ml RGB plastic crates
*Power consumption (kW)***	79.2
Compressed (bar)	7
Output	Empty and filled 300ml RGB bottles and empty and filled 300ml RGB plastic crates

* All conveyors are powered by identical electric motors

** This is the true consumption from the grid

6.4 Process emissions

There are no direct process emissions i.e. none of the unit processes for the packaging of CSD in Glass and PET emit GHGs during their operations. For example the blow moulder does not emit any GHGs during its normal production operation.

6.5 Statutory and fugitive emissions

Table 29 summarises the key utilities which are related to the CSD packaging process in Glass and PET containers and which generate statutory and fugitive emissions.

Table 29: Key fugitive emissions for CSD packaging process in Glass and PET containers

Utility	Glass	PET	Energy source
Power to run the unit processes	✓	✓	Electricity grid
Coal boilers for steam	✓	×	Coal
40 bar pressurised air	×	✓	Electricity grid
7 bar pressurised air	✓	✓	Electricity grid
Chilled water	✓	✓	Electricity grid
Chlorinated water	✓	✓	Electricity grid

As mentioned in section 6.1.6, the fugitive emissions associated with the 7 bar pressurised air, chilled and chlorinated water are similar (same machinery is used) for both CSD packaging processes in Glass and PET containers and hence are excluded from the analysis.

6.6 Material inputs to the CSD packaging process and their GHG emissions

Table 30 shows the main packaging raw material requirements for the CSD packaging process in Glass and PET containers.

Table 30: Main primary and secondary packaging material differences for Glass and PET CSD packaging process

Material	Glass	PET
Aluminium crown	✓	×
HDPE cap	×	✓
PP label	×	✓
Glass bottle	✓	×
PET preform	×	✓
LDPE case shrink wrap	×	✓
HDPE crate	✓	×
LDPE pallet wrap	×	✓
CSD liquid	✓	✓
Wooden pallet	✓	✓
HDPE crate banding	✓	×

Material that is common for the two types of containers will not be considered in the analysis as it is a comparative study and common factors need to be excluded.

Table 31 shows the weight of the different main packaging raw materials for the CSD packaging process of 300ml Glass and 500ml PET in terms of g/hl as well the related grams CO_2e/hl for a finished (fully packaged) container. The grams CO_2e are based on data from published sources. Direct access to the most recent databases come a great cost, which is not budgeted for.

Table 31: g/hl and related CO2e in g/hl for the different raw materials for Glass and PET

	300ml RGB Glass		**500ml PET**		
Raw material	g/hl	g CO2e/hl	g/hl	g CO2e/hl	*Source of the data*
Aluminium Crown	683	2411	N/A	N/A	*David amiyenu, EPA*
HDPE Cap	N/A	N/A	400	192	*David amiyenu, EPA*
PP Label	N/A	N/A	60	28	*David amiyenu*
Glass bottle	101000	13130	N/A	N/A	*Simon Berry*
PET preform	N/A	N/A	4230	2369	*Company investigated, EPA*
LDPE Case shrink wrap	N/A	N/A	417	246	*Company investigated*
HDPE Plastic Crate	13889	6667	N/A	N/A	*Simon Berry*
LDPE Pallet wrap	N/A	N/A	39	23	*David amiyenu*
HDPE Crate banding	86	41	N/A	N/A	*David amiyenu*

6.7 Main utilities for the Glass and PET CSD packaging process

Table 32 summarises the grams of CO_2e for the main utilities required for the Glass and PET packaging process.

Table 32: kWh/hl and related CO2e in g/hl for the different utilities for Glass and PET

	300ml RGB Glass		**500ml PET**		
Raw material	kWh/hl	g CO2e/hl	kWh/hl	g CO2e/hl	*Source of the data*
Coal burned in boilers for steam	215	209000	N/A	N/A	*Company investigated, EPA, GHG protocol*
40 bar pressurised air	N/A	N/A	2,6	3000	*Company investigated, GHG protocol*

6.8 Dynamic model analysis observations

Only the main types of CSD packaging containers are compared in the model analysis. These are containers which have been used by the business for many years and are not likely to change in the future due to marketing demand.

Table 33: Packaging container sizes used in the model analysis

Glass (ml)	PET (ml)
1250ml	2000ml

Table 34 shows a summary for the unit processes on the 1250 Glass packaging line.

Table 34: 1250ml Glass packaging process' unit processes

UNIT PROCESS	POWER CONSUMPTIONS		SPEED		POWER SOURCE
De-palletiser	kW	27,74	bph	26850	Purchased Electricity
Crate unpacker	kW	15	bph	22500	Purchased Electricity
Crate rinser	kW	5	bph	22500	Purchased Electricity
Bottle washer	kW	15,2	bph	21000	Purchased Electricity
Filler	kW	7,6	bph	18000	Purchased Electricity
Crate packer	kW	15	bph	20000	Purchased Electricity
Palletiser	kW	36,48	bph	23500	Purchased Electricity
Bottle conveyors	kW	79,2	bph	20000	Purchased Electricity

The bottle washer on the 300ml RGB line is the same for the 1250ml RGB. However, the speed of the bottle washer is reduced when running the larger 1250ml RGB.

Table 35 shows a summary for the unit processes on the 2000ml PET packaging line.

Table 35: 2000ml PET packaging process' unit processes

UNIT PROCESS	POWER CONSUMPTIONS		SPEED		POWER SOURCE
Blow moulder 1 power	kW	120	bph	10800	Purchased Electricity
Blow moulder 2 power	kW	122,4	bph	12240	Purchased Electricity
Air conveyor and silo	kW	98	bph	24000	Purchased Electricity
Unscrambler	kW	4,6	bph	32400	Purchased Electricity
Labeller 1	kW	65	bph	24000	Purchased Electricity
Labeller 2	kW	65	bph	24000	Purchased Electricity
Rinser and filler	kW	38,38	bph	24000	Purchased Electricity
Bottle conveyor	kW	18,5	bph	51840	Purchased Electricity
Case shrink wrapper	kW	215	bph	29376	Purchased Electricity
Pack conveyor	kW	38	bph	51840	Purchased Electricity
Palletiser	kW	48,5	bph	43200	Purchased Electricity
Stretch wrapper	kW	12	bph	117816	Purchased Electricity

The packaging raw materials and the main utilities for the 1250ml Glass and the 2000ml PET are almost identical to the 300ml Glass and 500ml PET, respectively, with the sole exception of the container size and 1250ml Glass plastic cap.

7. Results and Discussion

The purpose of this section is to review the CED and GWP results with respect to the Glass and PET CSD packaging processes. Initially unit processes' CED and GWP are analysed. This is followed by examining the main packaging raw materials' GWP for the two processes. Afterwards, the main utilities' CED and GWP are compared and discussed. Finally the overall CED and GWP in terms of direct and indirect contributions for the two packaging processes are analysed.

7.1 PET and Glass CSD packaging process unit processes' CED

The CED in terms of kWh/hl for the 500ml PET CSD packaging process' unit processes is shown in Figure 23:

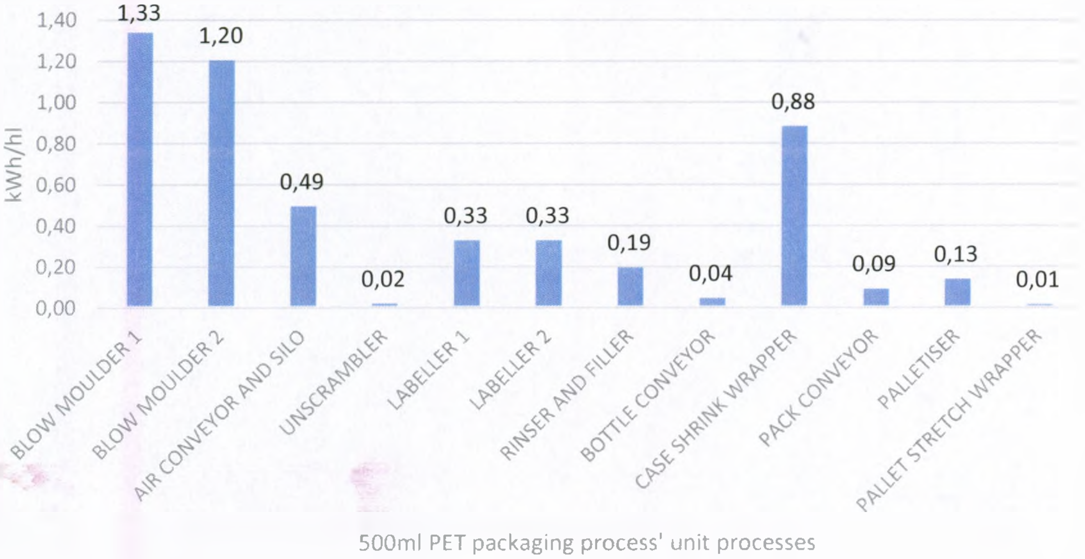


Figure 23: 500ml PET CSD packaging process' unit processes CED

The total CED for the 500ml PET CSD packaging process as a result of unit processes alone is calculated to be 5.04kWh/hl. Purchased electricity is used as an energy supply for all the unit processes on the PET CSD packaging line. The blow moulders consume the most kWh/hl, 1.33kWh/hl and 1.2kWh/hl, respectively. This amounts to 50% of the CED. The case shrink wrapper, which consumes 0.88kWh/hl, amounts to 18% of the CED. Together the blow moulders and the case shrink wrapper contributes to 68% of the CED for the 500ml PET CSD packaging process. Therefore, business efforts in reducing the energy consumption in these unit processes will be significant in bringing the CED down.

These types of machines require a tremendous amount of electricity to heat up electrical components which in turn generate heat which is used for production. Research points out that packaging line machinery OEMs corporations like Sidel, are encouraging the use of PET through their continuous breakthrough technologies which include innovations such as eco-ovens, reducing energy requirement by up to 45%, (Sidel, 2015). The business can consider replacing the heating elements in its blow moulders and case shrink wrapper with more efficient ones, which will consume less energy.

The speed of the case shrink wrapper (48 960bph) is 22% higher than the bottleneck's speed (40 000bph). During the research it was observed that the case shrink wrapper is often left operating at full capacity. The faster the case shrink wrapper runs, the faster it needs to heat the plastic shrink wrap over the bottles and hence it requires more power. Therefore, conducting a further study, which focuses on determining the optimum case shrink wrapper operating speed, may result in energy reductions.

The energy breakdown for the 300ml CSD Glass packaging process' unit processes is shown in Figure 24:

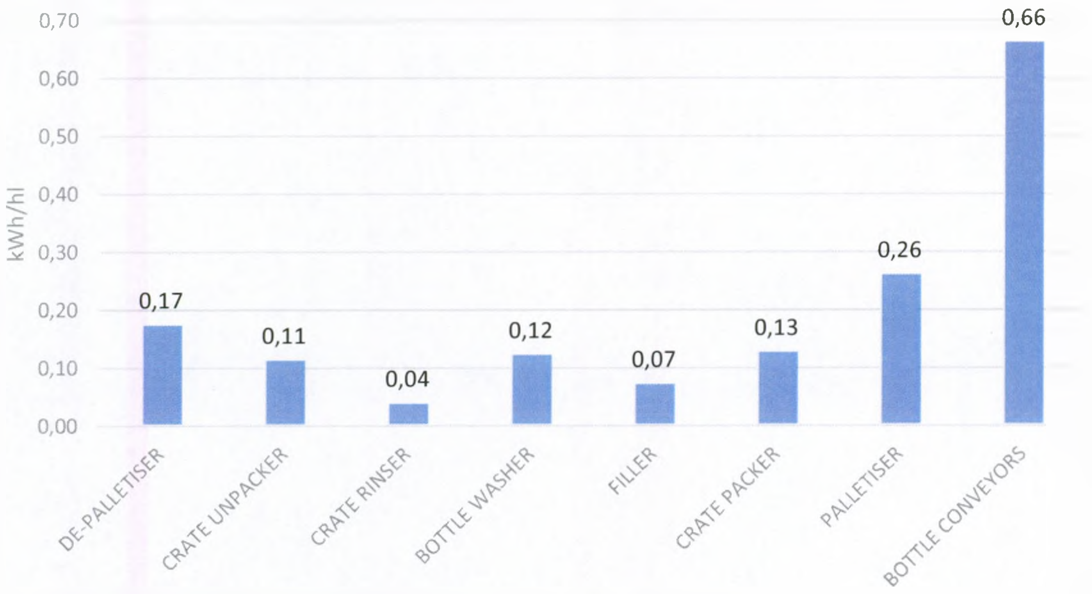


Figure 24: 300ml Glass CSD packaging process' unit processes CED

The total CED for the 300ml Glass CSD packaging process as a result of unit processes alone is calculated to be 1.56kWh/hl. Purchased electricity is used as an energy supply for all the unit processes on the Glass CSD packaging line. The bottle conveyors consume the most – 0.66kWh/hl. This amounts to 42% of the CED. The bottle conveyors, which transport the Glass bottles from one unit process to another, are powered by electric motors. Replacing existing electric motors with more efficient equivalents will have the biggest impact in reducing CED.

Figure 25 shows the number of unit processes for PET and Glass CSD packaging process.

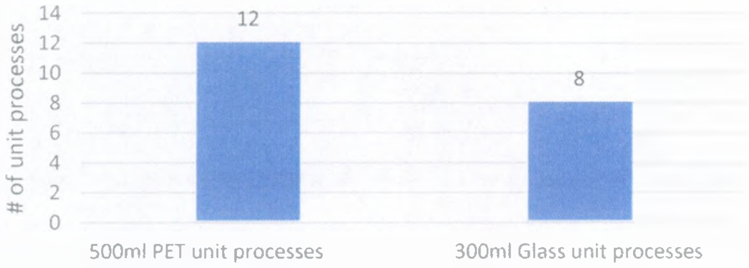


Figure 25: Unit processes for the PET and Glass CSD packaging processes

500ml PET CSD packaging process has 12 unit processes while 300ml Glass CSD packaging process has 8 unit processes. The business can try and optimise the number of unit processes on its PET packaging line by designing the unit processes better around the packaging line bottleneck (filler). This will eliminate the need for the silo, bottle unscrambler and some electric motors, which are currently used to compensate for the flaw in design and in turn reduce the CED for the PET packaging process.

Figure 26 compares the CED for the PET and Glass CSD packaging process` unit processes.

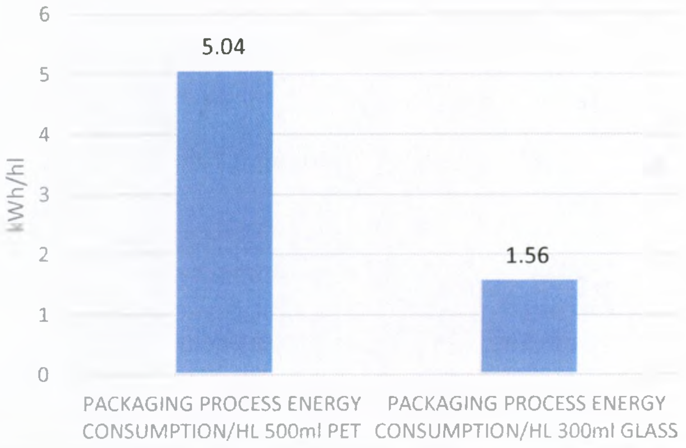


Figure 26: 500ml PET vs. 300ml Glass CSD packaging process' unit processes CED from purchased electricity

The total CED from purchased electricity for the PET CSD packaging process is 5.04kWh/hl and 1.56kWh/hl for Glass. 3.2 times more purchased electricity is used by the unit processes on the PET packaging line than the unit processes on the Glass packaging line. Therefore, packaging CSD in PET is a lot more energy intensive than packaging CSD in Glass. Based solely on this result, the business should convert all of its packaging lines to Glass. As mentioned earlier this will only be the case if no energy efficiency improvements and/or alternative energy sources are used. However, the business should not do the conversion based solely on the unit processes' CED result, but rather evaluate the CED for the whole process.

The impact on the business' carbon tax as a result of the CED for the CSD packaging processes in Glass and PET is zero. This is because carbon tax is only applicable to direct emissions from the process. The upstream supplier will be the one directly affected by carbon tax as it incurs direct emissions from burning coal to generate power. Therefore the business will be indirectly affected as upstream supplier may increase the cost of its service to compensate for its incurred carbon tax. The business can mitigate this risk by investigating alternative energy sources, which will have less of impact in terms of indirect carbon tax.

7.2 PET and Glass CSD packaging process unit processes' GWP

Figure 27 shows the GWP for the 500ml PET and 300ml Glass CSD packaging processes' unit processes, as a result of purchased electricity.

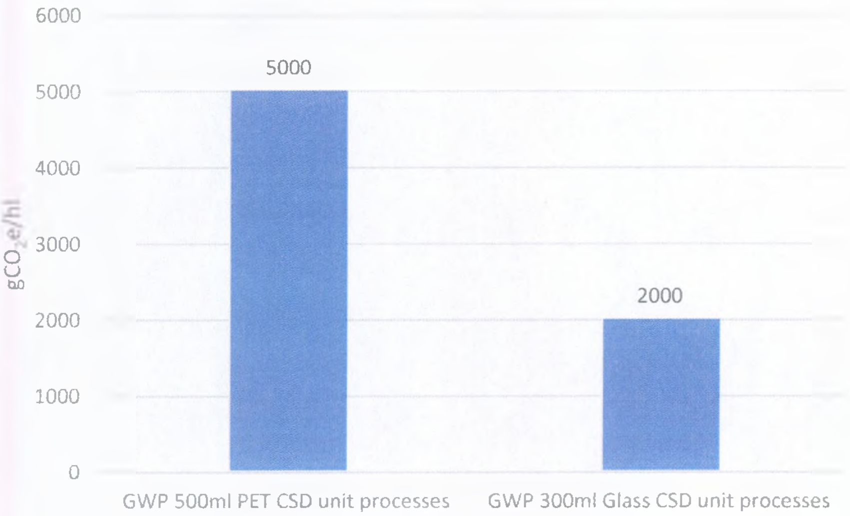


Figure 27: GWP for CSD packaging process' unit processes of 500ml PET and 300ml Glass

The GWP for the 500ml PET CSD packaging process' unit processes is calculated as 5000gCO_2e/hl and the GWP for the 300ml Glass CSD packaging process' unit processes as 2000 gCO_2e/hl. Packaging CSD in PET therefore results in 2.5 times more CO_2e emissions than packaging it in Glass. It can be noted that the higher the kWh/hl, the higher the kgCO_2e/hl will be. It is important to highlight that the aforementioned emissions will not contribute directly to the business' carbon tax, because those emissions are incurred by the upstream purchased electricity supplier. Hence it is important, from cost point of view, for the business to work on optimising its energy usage and look for alternative sources of energy other than purchased electricity.

7.3 PET and Glass CSD packaging process key raw materials CED and GWP

Main CSD packaging process raw materials are supplied to the business ready to be used by the unit processes on the respective packaging lines. The CED for these raw materials is therefore not calculated as it is outside of the scope for the study. The GWP for these materials is however calculated based on theoretical factors. Figure 28 shows the main materials' usage in terms of g/hl for the 500ml PET CSD packaging process.

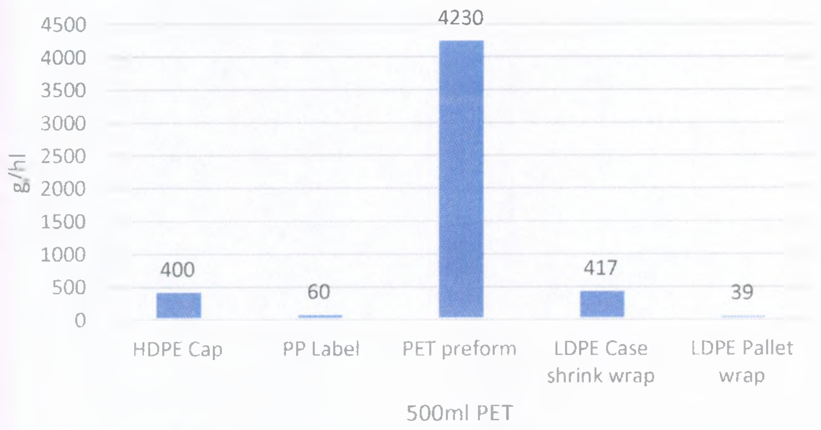


Figure 28: 500ml PET CSD packaging process main materials usage g/hl

The total g/hl of main raw materials for the 500ml PET CSD packaging process is calculated as 5146g/hl. The PET preform is the heaviest component of the fully packaged 500ml PET container - 4230g/hl of CSD.

The GWP in terms of gCO_2e/hl for the 500ml PET CSD main packaging raw materials is shown in Figure 29:

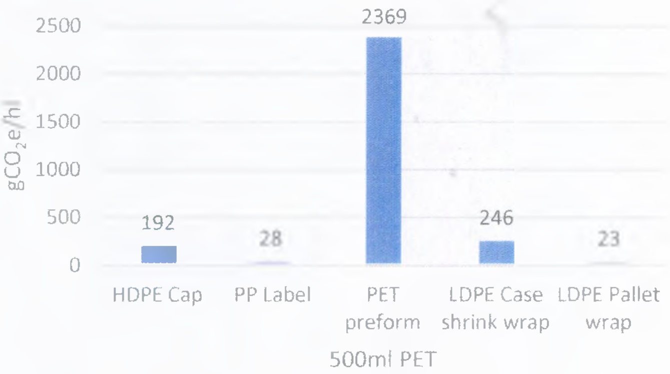


Figure 29: 500ml PET packaging process main raw materials' GWP

The total GWP for the 500ml PET CSD packaging process main raw materials is calculated using published data (EPA USA, 2015) and it has a value of 2858gCO$_2$e/hl. The 500ml PET preform has the highest GWP – 2369gCO$_2$e/hl. Reducing the weight of the 500ml PET preform will have the greatest effect on the GWP of the packaging process of CSD in PET containers. Although GWP due to material manufacture will not affect the company's carbon tax directly, it will have indirect cost implications, similar to those of purchased electricity. PET preform suppliers will incur this taxation instead and in turn will raise their prices to remain profitable. This will result in higher material cost to the business and hence it will negatively impact its profit margin.

Poor PET recycling in South Africa may require that new raw materials are always used for PET preforms manufacture, therefore further increasing upstream supplier GWP. The chemical composition of PET inherently requires environmentally costly materials (EPA USA, 2015), which can be replaced by greener options with technology advances and new scientific research. It is therefore important that the business together with suppliers continuously look for opportunities to reduce PET preform weight, material composition and/ or rate at which material is recycled and fed back into the system.

Figure 30 shows the main materials' usage in terms of g/hl for the 300ml Glass CSD packaging process.

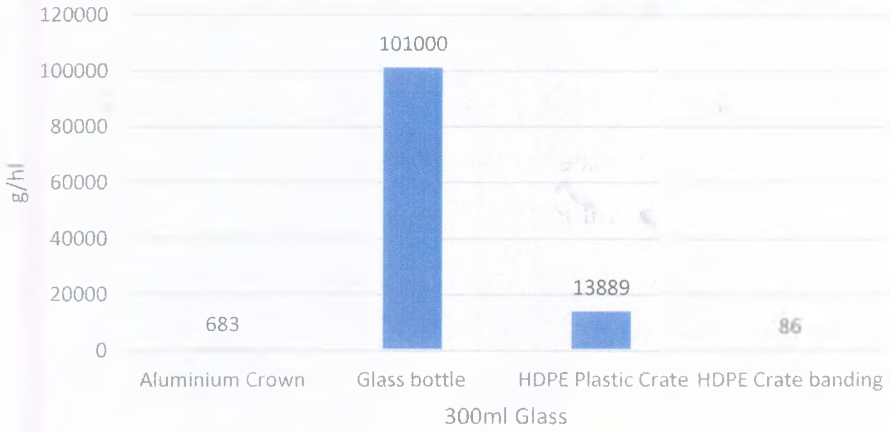


Figure 30: 500ml PET CSD packaging process main materials usage g/hl

The total g/hl of main raw materials for the 300ml Glass CSD packaging process is calculated as 115 658g/hl. The 300ml Glass bottle is the heaviest component of the fully packaged 300ml Glass container – 101 000g/hl of CSD.

The GWP in terms of gCO_2e/hl for the 300ml Glass CSD main packaging raw materials is shown in Figure 31.

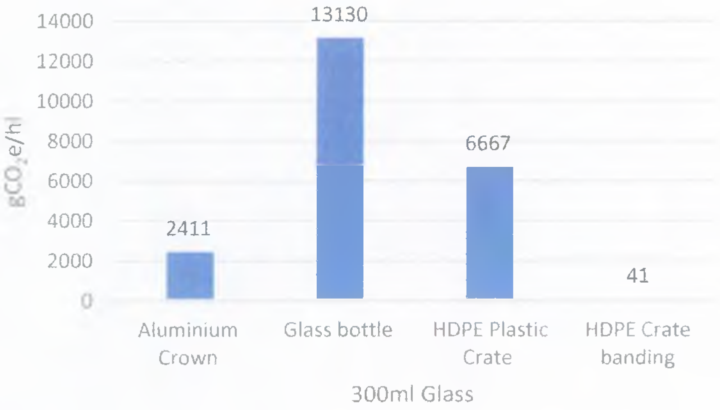


Figure 31: 300ml Glass packaging process main materials' GWP

The total GWP for the 300ml Glass CSD packaging process main raw materials is calculated using published data (EPA USA, 2015) and it has a value of 22 249gCO_2e/hl. The 300ml Glass bottle has the highest GWP – 13 130gCO_2e/hl. The HDPE plastic crate has the second highest GWP – 6667gCO2e/hl. Reducing the weight and changing the material composition of the 300ml Glass bottle and HDPE plastic crate will have the greatest effect on the GWP of the packaging process of CSD in Glass containers. Similarly to the PET preform discussion, the 300ml Glass bottle and HDPE plastic crate GWPs are expected to have a negative indirect effect on the business' profit margin whenever a new batch of these materials is introduced to the system. The return rate of 300ml Glass bottles and HDPE plastic crates is currently within target levels (20 cycles), according to information supplied by the business under investigation. Therefore the indirect effect on the business' profit margin will be very small in comparison to the 500ml PET counterpart, as discussed in the aforementioned paragraphs. Nonetheless, investigation into lighter, better composed and environmentally friendlier Glass bottles and plastic crates should be conducted between the business and its upstream suppliers.

The GWP comparison between the 300ml Glass and 500ml PET CSD packaging process main raw materials is shown below. Figure 32 shows the gCO_2e/hl for Glass vs. PET assuming new raw materials ejections is required every time. Figure 33 shows the gCO_2e/hl for Glass vs. PET, as per company current operations.

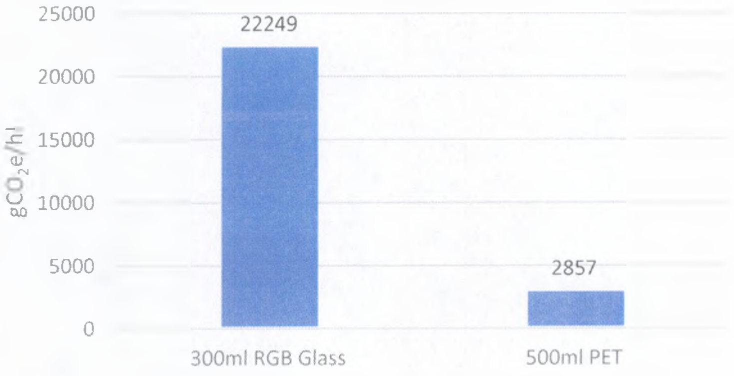


Figure 32: 300ml Glass vs. 500ml PET packaging process main raw materials GWP, assuming new injections every production cycle

Figure 33 shows the GWP of 300ml Glass when new RGB and HDPE plastic crates are injected into the system every 20 cycles. 500ml PET raw materials are always injected in full and the GWP for 20 cycles per hl is also shown below.

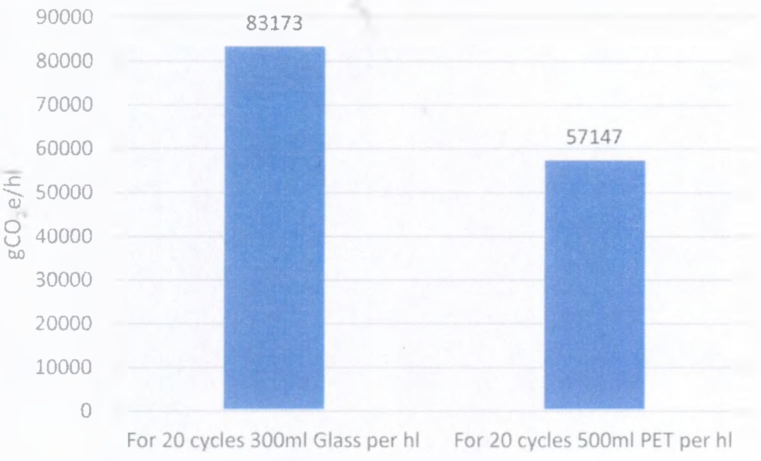


Figure 33: 300ml Glass vs. 500ml PET main packaging raw materials GWP per 20 cycles per hl

Initial manufacture of 300ml Glass main packaging raw materials (22 248gCO_2e/hl) emits 7.8 times more GHGs than manufacture of 500ml PET main packaging raw materials (2857gCO_2e/hl). However, this assumes that new Glass and PET containers are produced all the time. This is not the case as Glass containers and HDPE plastic crates are returned to the business (97%), which means that only continuous supply of new Aluminium crowns is required for CSD production with minimum (3%) injection of new Glass and HDPE crates. The number of cycles an RGB and an HDPE plastic crate remain in circulation before it can no longer be used is 20, as provided by the business. Thus GWP for 300ml Glass packaging raw materials over 20 cycles would be 83 173gCO2e/hl and for 500ml PET – 57 147gCO2e/hl.

The GWP for 300ml Glass packaging raw materials is thus 1.5 times greater than its 500ml PET counterpart. Therefore, the business needs to drive its market to achieve 100% returns of Glass and HDPE plastic crates. Co-operation with upstream suppliers and downstream customers on projects which can further increase this number of life cycles before a bottle and crate is destroyed is necessary to minimise the indirect effect of GWP due to new bottle and crate manufacture on the business.

Reducing the weight and improving the material composition of the bottle and crate will also have a positive impact on indirect carbon tax cost to the business. Lastly, the business should seek an alternative to Aluminium crowns as they are environmentally costly and a greener alternative will have a potential 2411gCO_2e/hl reduction in GWP for Glass.

7.4 PET and Glass CSD packaging process main utilities CED and GWP

2.6kWh/hl is the HP (High Pressure) compressor consumption to generate 40bar pressurised air for use by the two blow moulders on the 500ml PET packaging line. This has an indirect impact on business cost as the emissions associated with generating this power come from purchased electricity. The HP compressor itself does not emit any GHGs during its operation. The 2.6kWh/hl can be reduced by investigating more efficient compressor alternatives as well as compressed air transportation systems.

The coal boiler used to generate steam for the bottle washer on the 300ml Glass packaging line contributes to direct emissions on site and thus has a direct impact on the business` carbon tax. Figure 34 shows the CED for the HP compressor and the boiler. The kWh/hl for the boiler is a calculated equivalent which is based on the amount of coal used by the boiler to generate steam i.e. the consumption that would be required by the bottle washer if purchased electricity was used to generate steam directly. This conversion to kWh is done for comparison purposes.

Figure 34: CED for boiler and HP compressor

The CED for the boiler is 215kWh/hl and the one for the compressor is 2.6kWh/hl. If steam was generated by using purchased electricity instead of coal in boilers, as shown above, the Glass packaging process` utilities would require 83 times the amount of energy than the HP compressor. Steam is used for the sterilisation of the Glass bottle before it is filled with CSD. The business needs to investigate steam generation alternatives and steam recovery systems to ensure that it drives the equivalent power consumption of the boilers down and/or completely eliminates the need for them.

Figure 35 shows the GWP for the boiler and HP compressor. The boiler emits GHGs directly into the atmosphere during its operation and the GHGs as a result of running the HP compressor are indirect and come from upstream purchased electricity, which is generated by burning coal also.

Figure 35: GWP for boiler and HP compressor

Boilers emit 209 000gCO$_2$e/hl directly into the atmosphere while the HP compressor results in 3000 gCO$_2$e/hl of indirect emissions. 70 times more GHGs are emitted by the use of the boiler than the HP compressor. This makes the utilities of the Glass CSD packaging processes a lot more environmentally costly than PET's. Major focus is thus required by the business to drive projects which can reduce/eliminate these boiler emissions. Alternatives for Glass bottles sterilization must be investigated.

7.5 PET and Glass CSD packaging process overall CED and GWP

Figure 36 shows the overall CED for the Glass and PET CSD packaging process, which includes the unit processes and utilities, but excludes the main packaging raw materials, because they are produced off site and the CED associated with their manufacture is outside of the scope for this research.

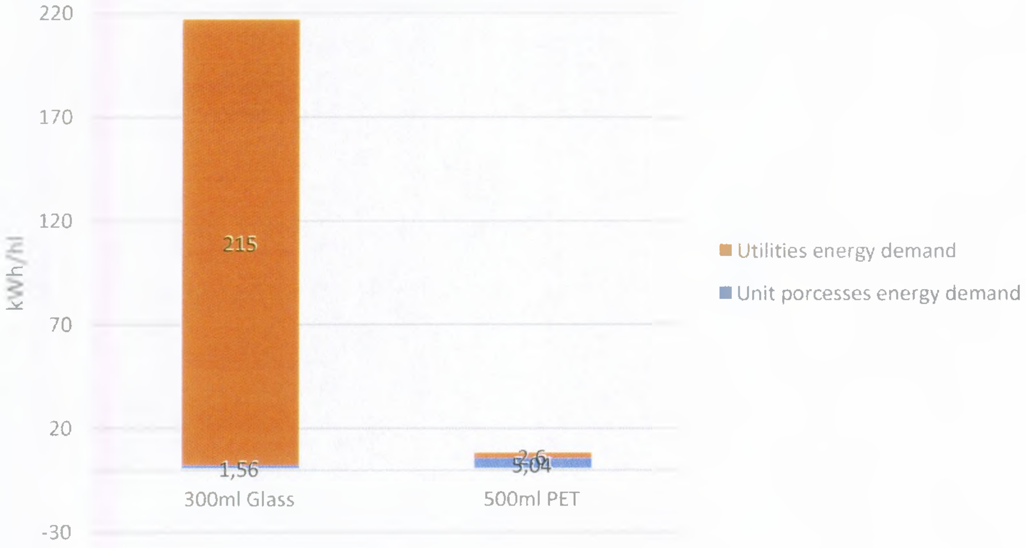


Figure 36: 300ml Glass vs. 500ml PET CED requirement

The CED for the 300ml Glass CSD packaging process is 216.56kWh/hl and the one for 500ml PET 7.64kWh/hl. 300ml Glass packaging process requires 28 times more kWh/hl than 500ml PET. This is a significant difference between the two processes. Furthermore, the utilities' CED for 300ml Glass contribute 99% to the total Glass CED, while the utilities for 500ml PET contribute 34% to the total PET CED.

Figure 37 shows the GWP for the Glass and PET CSD packaging process, which includes main packaging raw materials. It is important to note that both direct and indirect emissions are included.

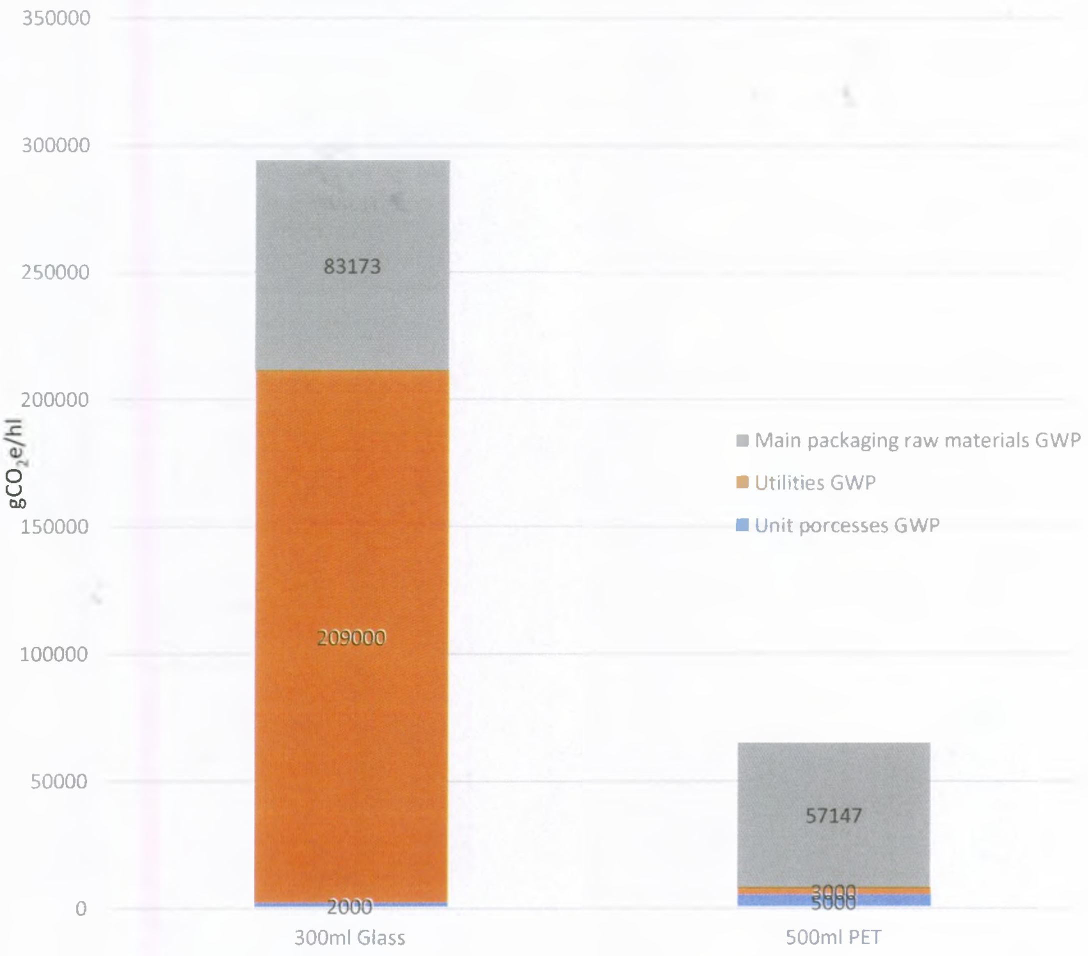


Figure 37: GWP for the 300ml Glass and 500ml PET CSD packaging process

CO_2 is the only GHG associated with the burning of coal in South Africa. (World Resource Institute, 2013) The overall GWP for 300ml Glass CSD packaging process is 294 173gCO_2e/hl and the GWP for 500ml PET is 65 147 gCO_2e/hl – 4.5 times less than Glass. The utilities and main packaging raw materials for 300ml Glass form 71% and 28% respectively of the total GWP for this packaging type of container.

The utilities and main packaging raw materials for 500ml PET form 5% and 88% respectively of the total GWP for this type of packaging container. The main focus areas for the business, should it decide to keep both types of packaging operations, would be around the raw materials and utilities used for Glass and raw materials used for PET, because reduction in these areas will yield the most improvement in working with a greener product.

The 300ml Glass utilities are the only direct contributors to business carbon tax. Packaging raw materials and unit processes for 300ml Glass and 500ml PET, both indirectly affect the business supplies (purchased electricity and raw materials) cost due to carbon tax increase in upstream organisations.

The direct GHG emissions by the business due to the 300ml Glass CSD packaging process is 71% and the remaining 29% have indirect GHG emissions. The direct GHG emissions for the 500ml PET CSD packaging process are 0%, with all the indirect GHG emissions resulting from purchased electricity and packaging raw materials' manufacture. It is interesting to point out that the direct GHG emissions due to the boiler alone generate 3.2 times the GHG than the whole of the 500ml PET CSD packaging process. Thus 500ml PET will result in lower carbon tax.

It can be concluded that 500ml PET is clearly the better packaging option from the CSD packaging process point of view, because it has both lower CED and GWP. The business should consider replacing all of the Glass packaging lines with PET equivalents. Before this is done, however, the scope of the PCF study conducted by this research needs to be expanded to cover the cradle to grave life cycle of Glass and PET containers for the business. This needs to be a business specific study and explicit conclusions form international studies cannot be directly applied because they are region and technology dependent. Thus, better supplemented decisions can be made by stakeholders when considering all life stages for the two types of containers.

7.6 PET and Glass CSD packaging process dynamic model analysis

An analysis was performed for two main reasons. The one was to show that the MS Excel model can be applied across all of the business' packaging lines and the second was to surface dive into the impact of using larger Glass and PET containers for the CSD packaging process. Only the unit processes' CED and GWP were compared. Figure 38 shows the overall CED for the 2000ml PET vs. 1250ml Glass packaging process.

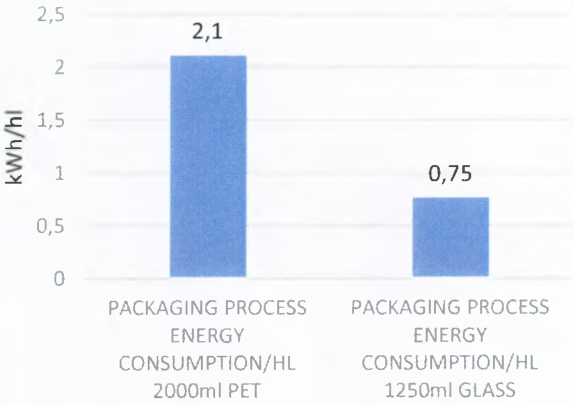


Figure 38: 2000ml PET vs. 1250ml Glass CSD packaging process' unit processes CED

The 2000ml PET CED (2.1 kWh/hl) is 2.8 times that of the 1250ml Glass (0.75 kWh/hl) CED CSD packaging process' unit processes. It is therefore cheaper in terms of purchased electricity to package CSD into Glass containers, assuming of course that only unit processes' energy demand is taken into account. It is interesting to compare these results to the ones of 300ml Glass and 500ml PET. Figure 39 illustrates this comparison.

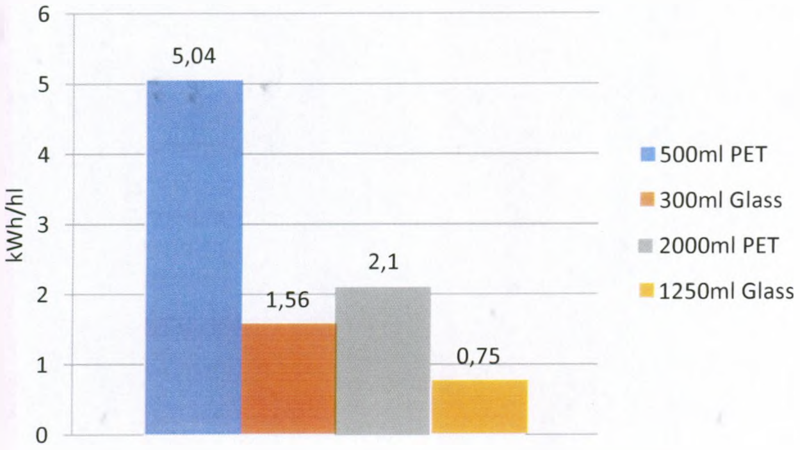


Figure 39: CSD of packaging process' unit processes CED of 500ml PET vs. 300ml Glass vs. 2000ml PET vs. 1250ml Glass

500ml PET packaging line's unit processes consume the most CED (5.04 kWh/hl), which is 2.4 times that of its 2000ml equivalent and 6.7 times that of 1250ml Glass. Also, unit processes for 300ml Glass (1.56 kWh/hl) consume 2 times more purchased electricity than its 1250ml Glass equivalent (0.75 kWh/hl). Based on these findings, it can be established that producing CSD in larger containers has a significant impact in reducing the purchased electricity drawn from the grid by the packaging lines' unit processes. It would be in the business' best interest to focus its marketing efforts in promoting more sales to come from larger CSD containers. This would make for a very good short term reduction in upstream purchased electricity supplier cost. It must be noted that although 1250ml Glass unit processes consume 0.75 kWh/hl, it should not be the organisation's packaging container of choice. This low CED number is expected to be offset drastically when main utilities' CED, as was shown for 300ml Glass and 500ml PET, is factored into the calculations.

Figure 40 shows the overall GWP for the 2000ml PET vs. 1250ml Glass packaging process.

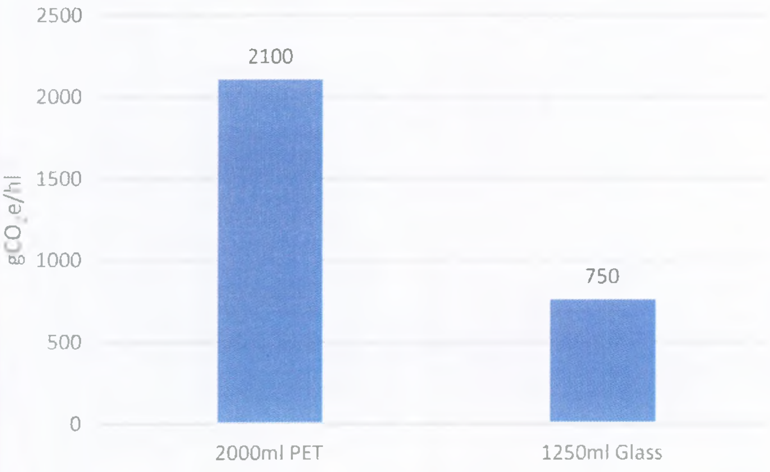


Figure 40: 2000ml PET vs. 1250ml Glass CSD packaging process' unit processes GWP

2000ml PET unit processes, indirectly via purchased electricity, emit 2100 gCO_2e/hl, which is 2.8 times that of the indirect emission during the packaging of CSD in 1250ml Glass containers. Similarly to the CED comparison, it would be interesting to show how the different container options rank up in terms of GWP. Figure 41 shows the 300ml Glass, 500ml PET, 1250ml Glass and 2000ml PET unit processes' GWP.

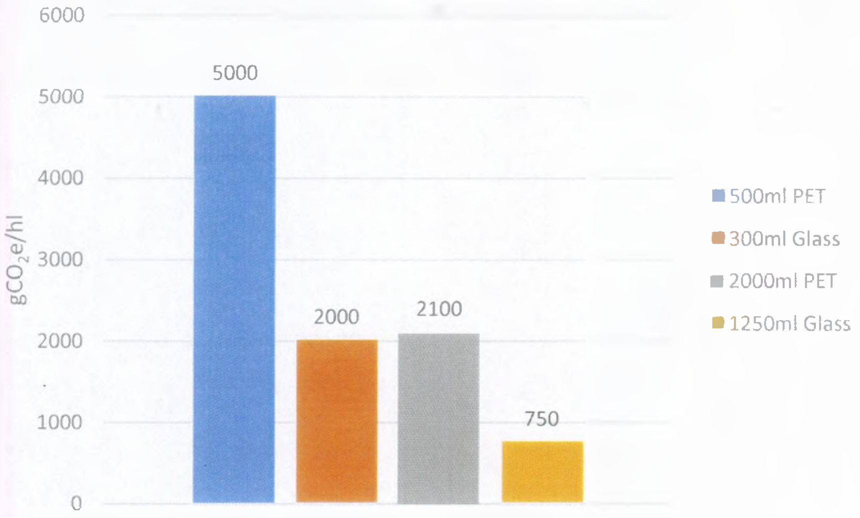


Figure 41: GWP of packaging process' unit processes CED of 500ml PET vs. 300ml Glass vs. 2000ml PET vs. 1250ml Glass

500ml PET unit processes' GWP (5000 gCO_2e/hl) is the highest across all four types of containers selected for comparison and is 2.4 times that of its 2000ml PET equivalent (2100 gCO_2e/hl). The GWP for 1250ml Glass has the lowest value (750 gCO_2e/hl). However, as discussed earlier when the CED for the four types of containers was compared, this value will be offset when including the emissions due to main utilities i.e. coal boilers.

It is interesting to point out that because the 300ml and 1250ml Glass packaging lines both make use of the same bottle washer, which is the most GWP intensive machinery on the Glass line, producing CSD in larger containers is expected to have a significant reduction in direct CO_2e emission by the business. However, when considering the 300ml Glass and 500ml PET overall GWP comparison, even halving this contribution will not favour the overall Glass packaging process' GWP.

The GWP for the 2000ml PET comes out as the best choice for the business, assuming raw material and utilities indirect emissions are similar to those of 500ml PET, because it indirectly emits half the gCO_2e/hl when compared to its 500ml PET equivalent and hence would add the least indirect carbon tax cost to the organisation. The benefit becomes clearer when these seemingly low values, which are expressed per the functional unit (hl), are factored into the annual sales of the business.

7.7 PET and Glass CSD packaging process overall discussion

The results of the study are expressed per functional unit (hl) of CSD. Although the GWP for the Glass and PET CSD packaging processes seem to consume little power and show a low GWP per hl value, the effects change quite drastically when the business' sales are factored in. As an example a 1 000 000hl/year business will result in 294 173 tonnesCO_2e per annum during its Glass operation and 65 147tonnesCO_2e per annum due to its PET operation for the 300ml and 500ml packaging containers alone. If other CSD SKUs are factored in, the emissions would be even higher. More accurate results can be achieved if the research model is applied across the business' SKU portfolio. This will provide the organisation with a complete representation of its CSD packaging processes' CED and GWP and hence enable stakeholders to better anticipate direct and indirect carbon tax costs.

The 300ml Glass CSD packaging process due to unit processes has half the environmental cost of its 500ml PET equivalent. The greatest environmental cost for both processes lies with the main utilities and packaging materials (99% for Glass and 93% for PET). Focusing on eliminating or reducing these values will therefore add the most value to the business. Short term, the business has to put strategies in place to ensure that the return rate of its empty Glass is as high as possible. Also, the material, which makes up the plastic crate for the 300ml Glass bottle, should be replaced with environmentally friendlier one, to reduce increased upstream supplier costs driven by carbon tax policy.

The business should focus on understanding the implications of changing container size in terms of possible market constraints and how this change would impact the business profitability. This would provide an insight into the true impact carbon tax would have on business profit. If possible, marketing efforts should be on driving sales in larger PET containers as those are expected to result in the least amount of carbon taxation for the business as well the least increase in upstream suppliers' cost when compared to Glass alternatives

Based on direct carbon tax impact, the Glass packaging process would contribute the most to the business' direct carbon tax. Should the business decide to keep its Glass packaging lines, due to market demand for example, its most important focus area must be reduction of the emissions by the coal boilers on site. Alternative energy sources should be considered first as well as improving the efficiency of the operation by investing in new bottle washer and/or better steam recovery system.

If the business does not make use of Glass bottles and instead considers NRB glass containers, the need for the energy and environmentally expensive bottle washer/sterilisation operation would fall away. This would take direct carbon tax implications away from the direct cost of the business. The burden will shift to the upstream NRB glass supplier instead. If this is the case the GWP for the Glass process would be around 86 000gCO_2e/hl, assuming the RGB and NRB have a very similar GWP potential during their manufacturing stages. In this case, PET CSD packaging process would still have a lower GWP value of 65 147 gCO_2e/hl, but the difference would not be 4.5 times as it is currently with the usage of 300ml RGBs. Hence, conducting a study, which investigates the usage of NRBs as opposed to RGBs, would add value to the business' stakeholders.

Since 88% of the 500ml PET CSD packaging process indirect GWP lies with the use of PET as the main raw material, the organisation will gain the most benefit in indirect cost reduction by focusing in this area first. Investigating ways into making the PET preforms lighter would be a good starting point. Long term, the business should focus on working with suppliers on projects which seek alternative and green material which will substitute the PET preform. Concurrently, the organisation needs to get more involved in PET recycling projects, which are expected to positively affect corporate governance and result in potential government subsidisations.

The use of non-PET containers only, which are made out of natural, very low carbon footprint materials, for the CSD packaging process is estimated to reduce the indirect GWP of the CSD packaging process by up to 47 000 gCO_2e/hl when compared to its 300ml Glass equivalent. This will make the choice of such PET alternatives a must for the organisation. Focused efforts on recycling of PET containers and research into replacing current PET preform composition with environmentally "clean" materials will have a great effect on the business. Its corporate governance would benefit because it will be seen as a green company by the public. Also, jobs are likely to be created due to resource demand for recycling and research into raw material alternatives. This may also result in the government subsidising the company for its efforts and economical contributions and hence lowering its carbon tax.

The reliance of purchased electricity usage by the organisation for its CSD packaging process is another area that stakeholders need to strategize around. Short term, more efficient light bulbs should be installed in the blow moulders on the PET packaging lines to reduce energy consumption. The opportunity of replacing the electric motors, which drive the bottle conveyors, with more efficient ones to save on purchased electricity demand should also be investigated. Alternative energy source, which supplies the energy hungry air compressors is likely to reduce the GWP of the PET packaging process. However, given the fossil fuel generated power dependency of the country, this would be a very challenging issue to resolve. Nevertheless, the business can attempt, via co-operation with suppliers and other industries, to influence the government to shy away from non-renewable resources for energy generation as part of a long term programme.

There seems to be a somewhat directly proportional relationship between the kWh/hl and the gCO_2e/hl when using the GHG calculation tool provided by (World Resource Institute, 2013). The tool shows that when burning coal only CO_2 is emitted as GHG. Since the tool is from an internationally credible source its output will be taken as true. Further supplier specific research would be required to better understand upstream GWP.

From the dynamic model analysis conducted, packaging in larger containers results in lower overall GWP values because of economies of scale. Also, the overall GWP results would still be in favour of PET, even if the PET and Glass containers are of identical volumetric capacity, because of the large GWP contribution of utilities and main raw materials required for Glass.

The business has the option to consider alternative packaging materials for its CSD packaging process. However, because the capital investment is in PET and Glass packaging lines only, such an investigation would be futile. For example, if further research concludes that an aluminium container is the "greenest" choice, replacing the entire existing infrastructure to accommodate this type of container will not make business sense due to the high conversion cost and rate of return on investment. The business should keep its existing Glass and PET packaging lines until a full blown LCA analysis is done, which will reveal the entire carbon footprint of Glass and PET packaging containers for the South African context.

Similar conclusions can be made when comparing the results of this research to the results obtained by (Flanigan, et al., 2013). The choice of packaging container when considering GWP into account largely depends on the raw materials chosen for its construction. For this research, raw materials' GWP for both Glass and PET containers form a significant part of the finished products' overall GWP. Comparing the results of this research to other academic literature, as found in the literature review section of this report, would not be fruitful, because there are numerous assumptions made for each study, which are not always disclosed in the publically available reports. Hence further comments regarding the similarities and differences in findings cannot be made at this stage.

8. Conclusions

The following conclusion can be drawn based on the results and discussion in the previous section:

1. The 500ml PET packaging process' unit processes were found to consume 5.04 kWh/hl
2. The 500ml PET packaging process' main utilities were found to consume 2.6 kWh/hl
3. The 300ml Glass packaging process' unit processes were found to consume 1.56 kWh/hl
4. The 300ml Glass packaging process' main utilities were found to consume 215 kWh/hl
5. Both the 500ml PET and 300ml Glass packaging process' main raw materials are produced off site and hence the CED associated with their manufacture was outside of the scope for the study and thus not quantified
6. The CED for the 300ml Glass packaging process, which includes main utilities and unit processes, was found to be 216.56 kWh/hl, which is 28 times that of 500ml PET (7.64 kWh/hl). The 500ml PET hence consumes the least amount of CED
7. For 500ml PET, 100% of the energy required for the CSD packaging process' unit processes and main utilities come from purchased electricity, which is obtained from the national grid. This electricity is generated by burning coal
8. For 300ml Glass, 99% of the CSD packaging process' CED was found to be drawn by coal boilers on site and the remaining 1% from the national grid
9. The GHGs associated with the CSD packaging process CED requirements all come from burning coal to generate power. The only GHG associated with burning coal in South Africa is CO_2. (World Resource Institute, 2013) The GWP for the 500ml PET CSD packaging process' unit processes, main utilities and raw materials was found to be 65 147 gCO_2e/hl, which is 4.5 times less than that for 300ml Glass (294 173 gCO_2e/hl)
10. The direct GHG emissions by the business due to the 300ml Glass CSD packaging process is 71% and the remaining 29% have indirect (off site) GHG emissions. The direct GHG emissions for the 500ml PET CSD packaging process is 0%, with all the indirect emissions resulting from purchased electricity and packaging raw materials manufacture. The 500ml PET CSD packaging process was thus found to result in lower carbon taxation to the business

11. Using larger PET (2000ml) and Glass (1250ml) containers was found to reduce the GHG emissions for the CSD packaging process. Using a 2000ml PET container for the CSD packaging process was found to be the best choice for the business

9. Recommendations

Recommendations for further academic research, which will build on the current study, are as follows:

1. Short term, the business should not devote time in conducting research on alternative packaging containers, which are incompatible with its existing infrastructure as the packaging lines' conversion would not make business sense in terms of return on investment
2. Due to site specific unit processes and utilities' set-ups and connections, the results from this study will not be directly applicable to another CSD manufacturing site and hence the study must be repeated across the whole business SKUs portfolio and all of its packaging lines across all of its sites in South Africa to fully quantify the CSD packaging process' PCF
3. Expand the scope of the study to include all life stages for the Glass and PET CSD packaging process and hence develop a full LCA
4. Conduct a detailed energy requirement study on the PET packaging lines' unit processes to find ways in reducing the overall power requirements
5. Conduct a detailed study on the Glass CSD packaging process' main utility to find ways in reducing the CED resulting from the bottle washer
6. Expand the study to consider the environmental impact of using water on the packaging lines

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Appendix A – South Africa's Carbon Tax

Table 36: South Africa's new carbon tax per industry (Parker & Gilder, 2015)

Sector	Basic Tax Free Threshold	Trade exposure allowance	Process emission allowance	Total	Offset percentage
Electricity	60%	-	-	60%	10%
Petroleum (coal / gas to liquid)	60%	10%	-	70%	10%
Petroleum - oil refinery	60%	10%	-	70%	10%
Iron & steel	60%	10%	10%	80%	5%
Cement	60%	10%	10%	80%	5%
Glass & ceramics	60%	10%	10%	80%	5%
Chemicals	60%	10%	10%	80%	5%
Pulp & paper	60%	10%	-	70%	10%
Sugar	60%	10%	-	70%	10%
Agriculture, Forestry and Land Use	60%	-	40%	100%	10%
Waste	60%	-	40%	100%	-
Fugitive emissions: Coal mining	60%	10%	10%	80%	5
Other	60%	10%	-	70%	10%

Appendix B - Data Accuracy and Reliability Standards Used as a Guideline

DATA

The accuracy of the study is only as good as the quality of input data. The development of methodology for the collection of data is essential to obtaining quality data. Careful adherence to that methodology determines not only data quality but also objectivity. Franklin Associates has developed a methodology for incorporating data

quality and uncertainty into LCI calculations. Data quality and uncertainty are discussed in more detail at the end of this section. Data necessary for conducting this analysis are separated into two categories: process-related data and fuel-related data.

Process Data

Methodology for Collection/Verification. The process of gathering data is an iterative one. The data-gathering process for each system begins with a literature search to identify raw materials and processes necessary to produce the final product. The search is then extended to identify the raw materials and processes used to produce these raw materials. In this way, a flow diagram is systematically constructed to represent the production pathway of each system. Each process identified during the construction of the flow diagram is then researched to identify potential industry sources for data. Each source for process data is contacted and worksheets are provided to assist in gathering the necessary process data for their product. Each worksheet is accompanied by a description of the process boundaries. Upon receipt of the completed worksheets, the data are evaluated for completeness and reviewed for any material inputs that are additions or changes to the flow diagrams. In this way, the flow diagram is revised to represent current industrial practices. Data suppliers are then contacted again to discuss the data, process technology, waste treatment, identify coproducts, and any assumptions necessary to understand the data and boundaries. After each dataset has been completed and verified, the datasets for each process are aggregated into a single set of data for that process. The method of aggregation for each process is determined on a case-by-case basis. For example, if more than one process technology is involved, market shares for these processes are used to create a weighted average. In this way, a representative set of data can be estimated from a limited number of data sources. The provided process dataset and assumptions are then documented and returned with the aggregated data to each data supplier for their review. At times, the scope or budget of an analysis do not allow for primary data collection. In this case, secondary data sources are used. These sources may be other LCI databases, government documents, or literature sources.

Confidentiality

Potential suppliers of data often consider the data requested in the worksheets proprietary. The method used to collect and review data provides each supplier the opportunity to review the aggregated average data calculated from all data supplied by industry. This allows each supplier to verify that their company's data are not being published and that the averaged data are not aggregated in such a way that individual company data can be calculated or identified.

Objectivity

Each unit process is researched independently of all other processes. No calculations are performed to link processes together with the production of their raw materials until after data gathering and review are complete. The procedure of providing the aggregated data and documentation to suppliers and other industry experts provides several opportunities to review the individual data sets without affecting the objectivity of the research. This process serves as an external expert review of each process. Also, because these data are reviewed individually, assumptions are reviewed based on their relevance to the process rather than their effect on the overall outcome of the study. Data Sources. The glass and steel process data sets used in this study were drawn from Franklin Associates' U.S. LCI database, which was developed using the data collection and review process described above. The plastics and aluminum process data was taken from the US LCI Database. Data for the fabrication of plastic bottle, cap and label were based on a combination of data published by PlasticsEurope and data collected by Franklin Associates for confidential industry sources. While these sources include European data, Franklin Associates assumes that the energy requirements and solid waste generation associated with the blow molding of plastic bottles is similar for Europe and North America.

Fuel Data

When fuels are used for process or transportation energy, there are energy and emissions associated with the production and delivery of the fuels as well as the energy and emissions released when the fuels are burned. Before each fuel is usable, it must be mined, as in the case of coal or uranium, or extracted from the earth in some manner.

Further processing is often necessary before the fuel is usable. For example, coal is crushed or pulverized and sometimes cleaned. Crude oil is refined to produce fuel oils, and "wet" natural gas is processed to produce natural gas liquids for fuel or feedstock. To distinguish between environmental emissions from the combustion of fuels and emissions associated with the production of fuels, different terms are used to describe the different emissions. The combustion products of fuels are defined as "combustion data." Energy consumption and emissions that result from the mining, refining, and transportation of fuels are defined as "precombustion data." Precombustion data and combustion data together are referred to as "fuel-related data." Fuel-related data are developed for fuels that are burned directly in industrial furnaces, boilers, and transport vehicles. Fuel-related data are also developed for the production of electricity. These data are assembled into a database from which the energy requirements and environmental emissions for the production and combustion of process fuels are calculated. Energy data are developed in the form of units of each primary fuel required per unit of each fuel type. For electricity production, International Energy Agency statistical records provided data for the amount of fuel required to produce electricity from each fuel source and the total amount of electricity generated from petroleum, natural gas, coal, nuclear, hydropower, and other (solar, geothermal, etc.). Literature sources and U.S. federal government statistical records provided data for the emissions resulting from the combustion of fuels in utility boilers, industrial boilers, stationary equipment such as pumps and compressors, and transportation equipment. Because electricity is required to produce primary fuels, which are in turn used to generate electricity, a circular loop is created. Iteration techniques are utilized to resolve this loop. In 2003, Franklin Associates updated their fuels and energy database for inclusion in the U.S. LCI database. With the exception of the electricity fuel sources and generation, this U.S. fuels and energy database is used in this analysis.

Data Quality Goals for This Study

ISO standards 14040 and 14044 detail various aspects of data quality and data quality analysis. These ISO Standards state: "Descriptions of data quality are important to understand the reliability of the study results and properly interpret the outcome of the study." These ISO Standards list three critical data quality requirements: time-related coverage, geographical coverage, and technology coverage. Additional data quality descriptors that should be considered include whether primary or secondary data were used and whether the data were measured, calculated, or estimated. The data quality goal for this study is to use the best available and most representative data for the materials used and processes performed in terms of time, geographic, and technology coverage. All fuel data were reviewed and updated in 2003 for the United States. Electricity fuel sources and generation meet all the data quality goals.

Data Accuracy

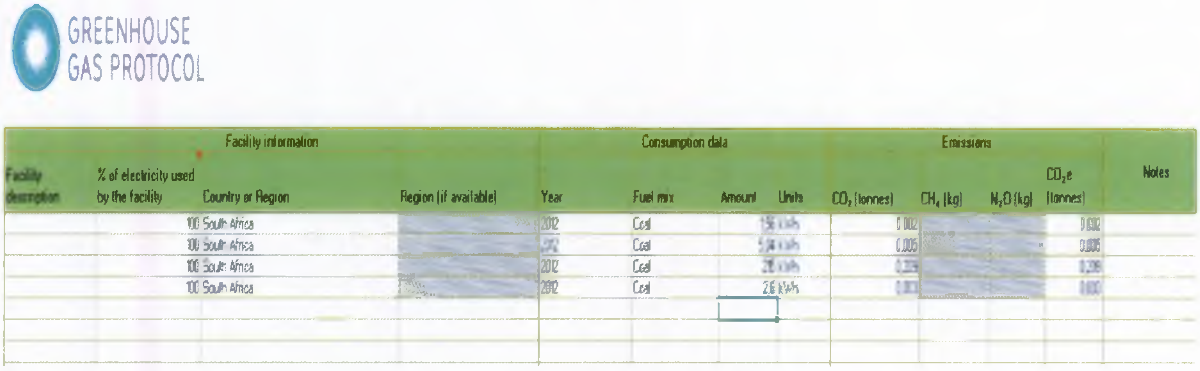
An important issue to consider when using LCI study results is the reliability of the data. In a complex study with literally thousands of numeric entries, the accuracy of the data and how it affects conclusions is truly a complex subject, and one that does not lend itself to standard error analysis techniques. Techniques such as Monte Carlo analysis can be used to study uncertainty, but the greatest challenge is the lack of uncertainty data or probability distributions for key parameters, which are often only available as single point estimates. However, the reliability of the study can be assessed in other ways. A key question is whether the LCI profiles are accurate and study conclusions are correct. It is important that the environmental profiles accurately reflect the relative magnitude of energy requirements and other environmental burdens for the various materials analyzed. The accuracy of an environmental profile depends on the accuracy of the numbers that are combined to arrive at that conclusion. Because of the many processes required to produce soft drink containers, many numbers in the LCI are added together for a total numeric result. Each number by itself may contribute little to the total, so the accuracy of each number by itself has a small effect on the overall accuracy of the total. There is no widely accepted analytical method for assessing the accuracy of each number to any degree of confidence. There are several other important points with regard to data accuracy. Each number generally contributes a small part to the total value, so a large error in one data point does not necessarily create a problem. For process steps that make a larger than average contribution to the total, special care is taken with the data quality. It is assumed that with careful scrutiny of the data, any errors will be random. That is, some numbers will be a little high due to errors, and some will be slightly low, but in the summing process these random high and low errors will offset each other to some extent. There is another dimension to the reliability of the data. Certain numbers do not stand alone, but rather affect several numbers in the system. An example is the amount of a raw material required for a process. This number will affect every step in the production sequence prior to the process. Errors such as this that propagate throughout the system are more significant in steps that are closest to the end of the production sequence. For example, changing the weight of an input to the fabrication of a container changes the amounts of the inputs to that process, and so on back to the quantities of raw materials.

" (Franklin Associates, 2009)

Appendix C – MS Excel Model (CD)

Appendix D – GHG protocol calculation tool example

Figure 42 is a snapshot of the (World Resource Institute, 2013) GWP calculation tool used by this report.



Facility information				Consumption data				Emissions				Notes
Facility description	% of electricity used by the facility	Country or Region	Region (if available)	Year	Fuel mix	Amount	Units	CO_2 (tonnes)	CH_4 (kg)	N_2O (kg)	CO_2e (tonnes)	
	100	South Africa		2012	Coal	[illegible]	kWh	0.002			0.002	
	100	South Africa		[illegible]	Coal	[illegible]	kWh	0.005			0.005	
	100	South Africa		2012	Coal	[illegible]	kWh	[illegible]			[illegible]	
	100	South Africa		2012	Coal	2.6	kWh	[illegible]			[illegible]	

Figure 42: GWP calculation tool example (World Resource Institute, 2013)