LIFE CYCLE SUSTAINABILITY ASSESSMENT IN THE UK BEVERAGE SECTOR

A thesis submitted to the University of Manchester for the degree of Doctor of Philosophy in the School of Chemical Engineering and Analytical Science

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CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABBREVIATIONS

ABV Alcohol by Volume

ADP Abiotic Depletion Potential

AP Acidification Potential

BBPA British Beer and Pub Association

BIER Beverage Industry Environmental Roundtable

BMI Body Mass Index

BSDA British Soft Drinks Association

BSI British Standards Institute

CDP Carbon Disclosure Project

COD Chemical Oxygen Demand

CSD Carbonated Soft Drink

DECC Department of Energy and Climate Change

DEFRA Department for Environment, Food and Rural Affairs

DQI Data Quality Indicator

EAA European Aluminium Association

EP Eutrophication Potential

ETP Ecotoxicity Potential

FAETP Freshwater Aquatic Ecotoxicity Potential

FBT Food, Beverages and Tobacco

FDF Food and Drink Federation

FDIN Food and Drink Innovation Network

GDI Gender Related Development Index

GDP Gross Domestic Product

GEM Gender Empowerment Measure

GGG Global Gender Gap

GHG Greenhouse Gas

GRI Global Reporting Initiative

GVA Gross Value Added

GWP Global Warming Potential

HDPE High Density Polyethylene

HFCS High Fructose Corn Syrup

HTP Human Toxicity Potential

IAS Institute of Alcohol Studies

ILCD International Reference Life Cycle Data System

ILO International Labour Organisation

IPCC Intergovernmental Panel on Climate Change

IPP Integrated Product Policy

ISO International Organisation for Standardisation

ITUC International Trade Union Confederation

LCA Life Cycle Assessment

LCC Life Cycle Costing

LDPE Low Density Polyethylene

LPA Litres of Pure Alcohol

LME London Metal Exchange

MAETP Marine Aquatic Ecotoxicity Potential

NDCI Nutrient Density to Climate Impact

NHC Natural Hydration Council

NNR Nordic Nutrition Recommendations

ODP Ozone Depletion Potential

PAS Publicly Available Standard

PET Polyethylene Terephthalate

POCP Photochemical Ozone Creation Potential

RSP Retail Selling Price

SETAC Society of Environmental Toxicology and Chemistry

SHDB Social Hotspots Database

TETP Terrestrial Ecotoxicity Potential

UNEP United Nations Environment Programme

UNESDA Union of European Soft Drinks Associations

UNHCR United Nations High Commissioner for Refugees

VA Value Added

VAT Value Added Tax

VHG Very High Gravity

WCED World Council on Environment and Development

WHO World Health Organisation

WRAP Waste and Resources Action Programme

WRI World Resources Institute

WSTA Wine and Spirit Trade Association

WTO World Trade Organisation

Life Cycle Sustainability Assessment in the UK Beverage Sector
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ABSTRACT

The aim of this research has been to develop an integrated life cycle methodology and assess the sustainability in the UK beverage sector considering environmental, economic and social aspects. The environmental impacts include climate change, resource depletion and emissions to air, land and water. The economic aspects considered are life cycle costs and value added. Social issues include health, labour and human rights and intergenerational issues. The environmental impacts have been assessed using life cycle assessment; economic impacts have been assessed using life cycle costing and value added analysis while social aspects have been assessed using relevant social indicators and social hot-spots analysis. The sustainability of the following beverages has been assessed: carbonated soft drinks, beer (lager), wine (red), bottled water and Scotch whisky. The environmental and economic assessments have first been carried out at the level of individual supply chains. The results have then been extrapolated using a bottom-up approach to the level of their respective sub-sectors and then, combining these results, to the UK beverage sector. This has been followed by the social assessment at the sectoral level.

The results of the assessment at the sectoral level show that UK consumption of the five beverages is responsible for over 3.5 million tonnes of CO_2 eq. emissions annually, with the carbonated soft drinks and beer sub-sectors accounting for 42% and 40% of the total, respectively. Total annual life cycle costs and value added are estimated at £1.3 billion and £15.8 billion, respectively. Production of packaging and raw materials are the major hot spots in the life cycle of the beverage supply chain for environmental and economic impacts. Strategies such as technological improvements, packaging optimisation as well as organic agriculture would lead to improved environmental and economic performance. The social hot spot assessment shows that China, Colombia and India are the countries likely to pose highest social risks. The findings of this study could help the government and beverage manufacturers to formulate appropriate policies and robust strategies for improving the sustainability in the UK beverage sector. The results could also help consumers to make more informed choices that contribute to sustainable development.

DECLARATION

No portion of the work referred to in the thesis has been submitted in support of an application for another degree or qualification of this or any other university of other institution of learning.

To

Augusta Ibazebo (1951 – 2010)

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1 INTRODUCTION

The significant progress towards economic development and improved human wellbeing over the past centuries has been enabled by rapid growth across different sectors of industry. Although the benefits of this rapid industrial growth can be seen in all aspects of life, from the wide range of consumer goods available, to the efficiency of transportation systems, as well as significant advances in communication technology, it has also brought with it associated environmental and socio-economic pressures which present challenges for sustainable development (WRI, 1998). Some of the issues include depletion of natural resources, increased energy demand, climate change largely attributed to anthropogenic greenhouse gas (GHG) emissions, toxic emissions to air, land and water leading to loss of biodiversity and other negative effects on human health and wellbeing. These concerns have provided an impetus for industry, governments and society as a whole, to make significant inroads towards creating a more sustainable economy.

The term 'sustainable development' is frequently cited in discussions concerning global development, the environment and society. The most widely used definition of sustainable development is given in the publication, 'Our Common Future', more commonly known as 'The Brundtland Report' which defines sustainable development as "that which meets the needs of the present without compromising the ability of future generations to meet their own needs" (WCED, 1987). In line with this interpretation of sustainability, the general consensus is that sustainable development must incorporate environmental, social and economic aspects. These three components are commonly referred to as the 'three pillars' of sustainability. This suggests that in order for any development effort, process or product to be considered sustainable, it must fulfil the conditions of being environmentally benign, economically viable and socially beneficial (Azapagic and Perdan, 2000).

Industry has been a key target for the implementation of a range of measures towards sustainable development in recognition of its role as a major contributor, not only to economic development, but also to resource depletion and other forms of environmental degradation (Azapagic and Perdan, 2000). Although significant progress has been made to improve the environmental performance of industry, it is widely acknowledged that social and economic aspects must also be taken into account in efforts to achieve a more sustainable economy (IChemE, 2003; Kloepffer, 2005). Since products are the major output of industrial activities, it therefore follows that sustainability should be the primary aim of product development and integrated product policy (IPP). The IPP is also at the heart of the European Union policy relating to the sustainability of products (European Commission, 2003). Therefore, the proper assessment and balancing of these components is requisite for the design of new or the improvement of existing products (Kloepffer, 2008). Furthermore, sustainable production and consumption are considered to be at the heart of the journey towards sustainable development (Andrews et al., 2009).

The importance of sustainability in the food and beverage sector cannot be overemphasised as it is a core element of the UK manufacturing sector, representing over 15% of manufacturing turnover and employment (FDF, 2010). Between 2005 and 2009, the UK beverage sector, an important component of the food and drink sector, recorded the average growth of 2.9%. This suggests that consumption of beverages in the UK is on the increase despite fluctuating market conditions. This growth, fuelled by growing consumption of beverage products, is expected to lead to intensified production activities along a vast number of supply chains. This will in turn lead to increased consumption of resources, generation of waste, and other environmental impacts such as climate change due to anthropogenic greenhouse gas (GHG) emissions. As an illustration of the critical and far-reaching nature of these issues, the Intergovernmental Panel on Climate Change (IPCC) and the UK Department for Environment, Food and Rural Affairs (Defra) predict that global climate change will impact negatively on the viability of ecosystems, food productivity, commodity prices and supply chains, as well as human health (IPPC, 2007; Defra, 2012).

Currently, it is not known how the beverage sector impacts on the environment apart from a few scant facts. For instance, it is estimated that the food and drink sector contributes around 11.6 million tonnes of CO_2 eq. emissions or 2% of the total UK greenhouse gas emissions (FDF, 2008; Defra, 2006). However, it is not clear how much the beverage sector contributes to this. It is also known that the beverage sector is one of the major consumers of packaging – in 2002, it accounted for over 4 million tonnes or 40% of the total packaging consumed in the UK (Key Note, 2003; Defra, 2005), consequently also contributing to significant packaging waste streams. The depletion of freshwater resources is another important issue which has recently come to the fore in discussions about sustainability. Global freshwater consumption has more than doubled since the 1940s and is expected to rise by another 25% by 2030 (The Environmentalist, 2012). The authors also observe that currently one-third of the world's population live in 'water-stressed' countries and this is expected to rise to two-thirds by 2050. Regarding the impact of water shortage on businesses, 60% of respondents of the Carbon Disclosure Project (CDP)[1] second annual survey reported exposure to water risk while more than 33% had already experienced water-related impacts with costs as high as $200 million (The Environmentalist, 2012). This issue is critical for the beverage industry as water forms the major ingredient in beverage formulations. Food and drink production and processing is also reported to be responsible for the majority of water use globally (Foster et al., 2006). In response to this challenge, the Beverage Industry Environmental Roundtable (BIER), a partnership of leading global beverage companies, has recently published a guide for the application of water footprinting tools and methodologies (BIER, 2011) aimed at facilitating a better understanding of water use in the beverage industry. There is also a dearth of information regarding other environmental impacts resulting from emissions to air, land and water from the beverage sector. Furthermore, there are very few studies illustrating the integration of environmental impacts of the beverage sector with social and economic issues such as employment, contribution to Gross Domestic Product (GDP), nutrition and consumer health in general.

Despite the significance of this sector, there is currently no methodology for understanding and assessing its sustainability in an integrated manner along the supply chain. Given that the beverage sector is a major contributor to the UK economy and a key player in the global import and export market, an integrated methodology for sustainability assessment would help the industry to measure and improve its level of sustainability as well as assist the government in formulating appropriate policies and other measures for making the sector more sustainable.

[1] The Carbon Disclosure Project (CDP), which is aimed at driving greenhouse gas emissions reduction by businesses, has recently expanded its focus to water (The Environmentalist, 2012).

Therefore, this research was formulated and carried out in an attempt to contribute towards this goal.

1.1 Research aims, objectives and novelty

The main aim of this research has been to develop an integrated methodology and assess the sustainability of the UK beverage sector. The specific objectives have been:

- to review the UK drinks sector and identify the main sustainability issues;
- to assess the environmental and economic sustainability of different beverage sub-sectors on a life cycle basis and identify the hot spots that could be targeted for improvements;
- to use the results at the sub-sectoral level and the UK market analysis to estimate the environmental and economic sustainability of the sector as a whole;
- to combine these results with the analysis of the social sustainability of the UK beverage sector; and
- to make recommendations to industry and policy makers for sustainability improvements in this sector.

The environmental and economic impacts have been assessed using a life cycle approach, considering the impacts of the beverage supply chain in its entirety, from production of agricultural inputs, agricultural production, beverage manufacturing, transport, retailing and waste disposal. Life Cycle Assessment (LCA), Life Cycle Costing (LCC) and Value Added (VA) analysis have been used as tools for these purposes. With respect to the sectoral analysis, the study demonstrates how the scope of the conventional product-based LCA and LCC methodology can be expanded to estimate the life cycle impacts of an industrial sector using a bottom-up approach rather than the top-down approach applied in the input-output LCA. Finally, the social assessment has involved the use of a number of social sustainability indicators applicable to this sector.

As far as the author is aware, this is the first example of such a study for the UK beverage sector. The main novelty of the research is in the following outputs:

- an integrated methodology for assessing the life cycle sustainability of the beverage sector, focused on the UK but also applicable to other countries;
- sustainability assessment and identification of improvement opportunities for the main beverage sub-sectors: carbonated soft drinks, bottled water, beer, wine and Scotch whisky; and
- application of the bottom-up life cycle approach to assess the sustainability at the level of the drinks sector.

The study focuses on the domestic production and consumption of beverages in the UK[2]; hence it excludes the sustainability impacts of beverages destined for the export market. Arguably, a consumption-based perspective more accurately captures impacts that can be attributed to UK activities. Furthermore, the final consumption of goods and services is the driving force of an economy and, therefore, offers opportunities for environmental management along product supply chains (Guinée et al., 2001). Another important point to note is that the beverage sector is split in terms of distribution channels into the 'on-trade' and 'take-home' markets. Only the latter is considered while the former, representing consumption in entertainment venues such as bars and restaurants, has been excluded from this work due to a lack of data.

As an introduction to the research objectives and methodology, an overview of the UK beverage sector is presented in Chapter 2 which discusses the economic, environmental and social aspects associated with this industry. This is followed by a description of the methodology developed and applied in this research in Chapter 3, while the results of the life cycle environmental and economic sustainability analyses of different beverage products are presented in Chapters 4 to 8. Chapter 9 draws upon and synthesises the findings for the five beverages as well as on literature data to estimate the social sustainability impacts at the sectoral level, incorporating environmental, economic and social aspects. The conclusions and recommendations for further research are presented in Chapter 10.

[2] The only exception is the case study of wine which considers the impacts of Australian wine destined for the UK market due to the fact that most of the wine consumed in the UK is imported.

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2 OVERVIEW OF THE UK BEVERAGE SECTOR

2.1 Introduction

Beverages are consumed for a variety of reasons ranging from maintaining the health and integrity of the human body to satisfying other utilitarian or physical needs. The beverage supply chain, consisting of a wide range of different products, is also associated with various sustainability issues, partly due to its dependence on other industrial sectors including agriculture, transport, energy and chemicals. In the agricultural sector, for instance, approximately two thirds of national output in the UK are utilised for food and drink production (FDF, 2010). Other sectors such as rubber and plastics, and basic metals are crucial components of the beverage supply chain, providing raw materials for packaging beverage products. Beverage manufacturers also rely on the chemicals sector for obtaining intermediate chemicals which are important components of beverage formulations, while the transport and energy sectors also play an indispensable role in the logistics of the beverage supply chain.

This chapter highlights the significance of the beverage sector for the UK economy. It also considers the growth in consumption and production activities within the sector as well as environmental and socio-economic impacts arising from production and consumption of beverages. In response to the need for a more sustainable beverage sector, policy measures and technological solutions, as well as industry and government targets for sustainability goals are highlighted. This information is used later in this work to help identify and assess the potential impact of strategies for sustainability improvements in the sector.

2.2 Sustainability impacts of the UK beverage sector

As indicated in Figure 2-1, the UK beverage sector is divided into the following sub-sectors:

i. beer;
ii. wine;
iii. spirits and liqueurs;
iv. other alcoholic drinks (including cider and flavoured alcoholic beverages);

v. soft drinks (including carbonated drinks, dilutable drinks, bottled water, fruit juices and still and juice drinks); and
vi. hot drinks (including teas, coffees, hot chocolate and malted drinks).

The sector was valued at £58.3 billion[3] in 2009 with alcohol[4] and soft drinks[5] reported to account for about 73% and 22%, respectively (Key Note, 2009) as shown in Figure 2-1.

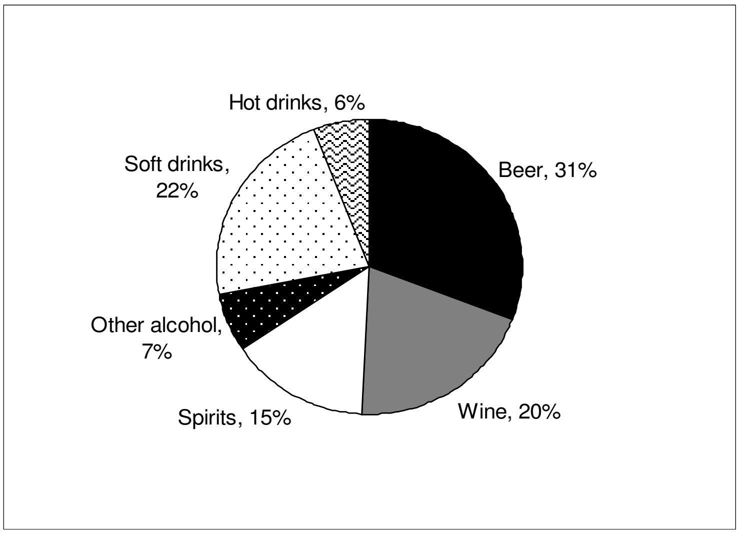

Figure 2-1 Distribution of the UK drinks sector by value in 2009 (Key Note, 2009; BSDA, 2009)

The sector grew by around 2.9% between 2005 and 2009 despite mitigating factors such as the economic recession, downward pressure on drinks prices and a series of poor summers (Key Note, 2009). For example, consumption of soft drinks in the UK increased from an estimated 13.9 billion litres in 2008 to 14.1 billion litres in 2009 (BSDA 2009, 2010). Consumption of alcoholic beverages in the UK also increased from approximately 9.4 to 10.7 litres of pure alcohol (LPA)[6] per adult[7] between 1994 and 2009 (IAS, 2010). This increased consumption of beverages has led to increased

[3] This refers to the total value of consumer expenditure on drinks in the UK at the retail price level.
[4] For the purposes of this study, alcoholic beverages comprise beer, wine and spirits.
[5] Soft drinks are classified using the categories defined by the British Soft Drinks Association into carbonates, dilutables, bottled water, fruit juice, and still and juice drinks.
[6] Clearances of pure alcohol have been determined using estimated average strengths for wine, beer and cider (IAS, 2010).
[7] Adult refers to people aged 16 and over from the Population Trends Spring 2008, published by the Office for National Statistics (IAS, 2010).

production in order to satisfy demand. This has in turn, intensified production and consumption of materials, emissions to air, land and water, as well as generation of significant amounts of waste along the beverage supply chain. For example, it was estimated that the drinks sector accounted for over 4 million tonnes of the packaging consumed in the UK in 2004 (Defra, 2005), food and drinks production and processing accounts for the majority of water use globally (Foster et al., 2006), and the food and drinks sector is estimated to be responsible for around 11.6 million tonnes of CO_2 eq. emissions or 2% of the total UK GHG emissions, although it is not clear how much the beverage sector contributes to this. Furthermore, very little is known about the beverage sector's contribution to other environmental impacts resulting from emissions to air, land and water. Beverage production and consumption activities also contribute to socio-economic impacts including consumer health issues such as nutrition, obesity and diabetes, alcohol-related diseases including liver cirrhosis, high blood pressure and heart disease, as well as impacts related to employment and social service provided by the beverage products. In the following sections, the sub-sectors which comprise the UK beverage sector are described in regard to consumption trends, market size, economic value, contribution to employment, consumer health impacts and contribution to environmental impacts.

2.2.1 Soft drinks

The UK soft drinks industry, which is largely driven and supported by modern consumer lifestyle and convenience, was estimated to be worth 14.6 billion litres and £13.9 billion in terms of volume and value, respectively in 2010 (BSDA, 2011). This huge consumption of soft drinks in the UK translates to an annual per capita consumption of around 229 litres. As shown in Figure 2-2, the UK soft drinks industry comprises of carbonated soft drinks, dilutables, bottled water, fruit juice and still and juice drinks. In the current study, the life cycle impacts of carbonated soft drinks and bottled water have been studied, while the impacts of fruit juice and still and juice drinks have been excluded from the study due to lack of data. More detail on the carbonated soft drinks and bottled water sectors in the UK are provided subsequently.

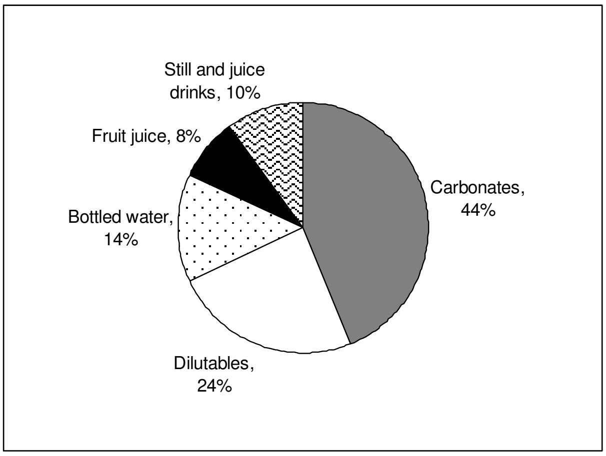

Figure 2-2 UK soft drinks sectors by volume 2010 (BSDA, 2011)

2.2.1.1 Carbonated soft drinks

Carbonated soft drinks are colloquially known as ‘fizzy drinks’ in the UK. They usually consist of water, sugar or other sweeteners, carbon dioxide, an acid and flavouring (BSDA, 2010; Key Note, 2011). Their popularity is reflected in the fact that, along with other soft drink variants, they account for 22% of the UK drinks market by value. Consumption of carbonated soft drinks in the UK, comprising of cola, fruit, lemonade, energy and other variants (see Figure 2-3), increased from 6.2 billion litres in 2004 to 6.4 billion litres in 2010. This translates to a per capita consumption of around 103 litres in 2010. This increasing consumption may be attributed to several factors including an increase in the UK population representing a growing consumer base[8], increase in household disposable income[9], the launch of new products and consumer perceptions. Polyethylene terephthalate (PET) bottles represent the most popular type of packaging for carbonated soft drinks, with 57% of the total volume of carbonated soft drinks packaged in PET. Cans and glass account for 26% and 3% respectively, while dispensers and other unspecified packaging account for 14% (see Figure 2-4).

The carbonated soft drinks sub-sector was valued at £8 billion in Retail Selling Price (RSP) in 2010 (BSDA, 2011), accounting for 57% of the total UK soft drinks market

[8] The population of the UK was 62.3 million in mid-2010, an increase of 0.8% on the previous year and an increase of 3.1 million compared with mid-2001 (Office for National Statistics, 2011).
[9] Household disposable income per capita increased from £13.572 in 2005 to £15,225 in 2009 (Key Note, 2011. Source: Economic and Labour Market Review, November 2010, National Statistics website).

by value (Key Note, 2011). In the UK, this sub-sector is dominated by multinational companies which are responsible for several brands of carbonated soft drinks including Coca Cola, Pepsi, Irn Bru, Dr Pepper, Schweppes and Britvic. Regarding socio-economic issues such as employment, specific figures for the number of people employed in the carbonated soft drinks industry are difficult to establish as soft drink manufacturers are usually associated with multiple categories of beverage products. However, as an indication of the employment levels in the sector, the six leading soft drink (including bottled water) manufacturing companies: Coca Cola Enterprises, Britvic UK, AG Barr, Cott Retail Brands, Red Bull and Nichols Plc, employ over 10,000 people in the UK (Key Note, 2011). The British Soft Drinks Association estimates that the workforce in the UK soft drinks industry amounts to around 12,000 people (BSDA, 2011) or around 0.5% of the UK manufacturing workforce[10].

Despite the carbonated soft drinks providing refreshment as well as the sector's contribution to the economy, their consumption has been associated with a range of negative social impacts. The most widely discussed include the growing problem of obesity[11] which may be attributed (not exclusively) to the intake of beverages containing high amounts of simple sugars and high-fructose corn syrup (HFCS) (Bray et al., 2004), as well as associated health issues such as cardiovascular risk (Kavey, 2010) and diabetes. The scale of the obesity problem is highlighted by the finding that the incidence of obesity has almost trebled in the last 20 years. In 2006, it was estimated that 22% of the UK population was obese (EIRIS, 2006). The industry and government response to consumer health issues is discussed later in this chapter. In relation to consumer health issues, the aim of this study has been to identify and highlight the issues relevant to the UK beverage sector. It is also important to note that the list of identified issues is by no means comprehensive.

Regarding the environmental impacts, the Waste and Resources Action Programme (WRAP) estimates that soft and hot drinks contribute around 344,000 tonnes of waste packaging to the UK household waste streams (Jenkin, 2010). This also has significant consequences for consumption of materials used in manufacture of

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[10] Based on the estimated 2.6 million people employed in the UK manufacturing sector in 2009 (BIS, 2010).

[11] A person is generally considered obese if they are overweight by 20 – 30% of their ideal body weight or has a Body Mass Index (BMI) of 30 or above (EIRIS, 2006).

packaging. However, the specific contribution from carbonated soft drinks is not given. Despite the growing concern in the beverage and other industries about the depletion of freshwater resources, there is little information on the water footprint of beverage products in the UK or in an international context. However, it has also been estimated that carbonated soft drinks require around 2.5 to 4 litres of water per litre of drink (Foster et al., 2006). Recently, a couple of studies have been carried out estimating the carbon footprints of carbonated soft drinks in the UK, one by Coca Cola (2010) and another by Tesco (2011). However, apart from the total carbon footprint values, there is little other information on the systems studied; furthermore, neither study considered any other environmental impacts.

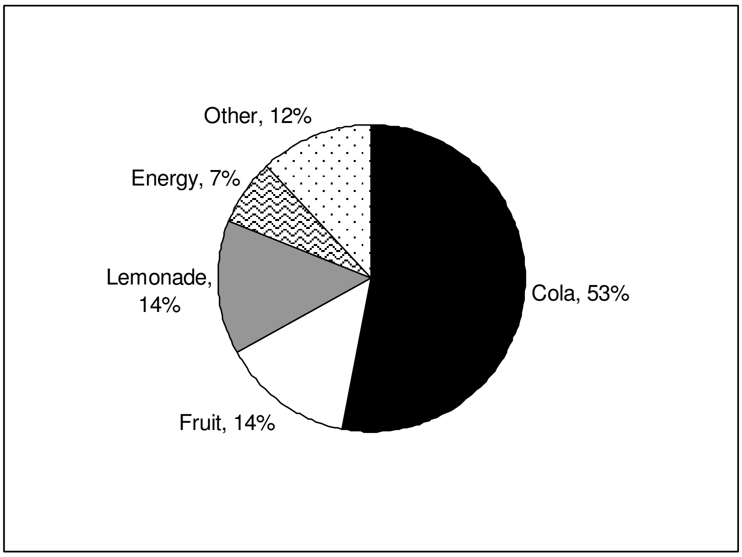

Figure 2-3 Carbonated soft drinks flavours by volume in the UK (BSDA, 2011)

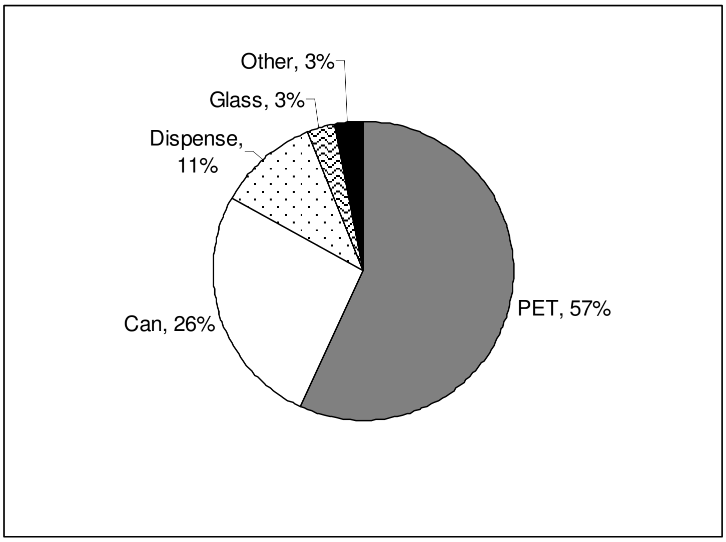

Figure 2-4 Carbonated soft drinks packaging by volume in the UK (BSDA, 2011)

2.2.1.2 Bottled water

The British Soft Drinks Association (BSDA) classifies the UK bottled water market into still bottled water, sparkling bottled water and still water coolers, available in the proportions 72%, 14% and 14%, respectively (Figure 2-5). Still water, as the name implies, does not contain any carbon dioxide, while sparkling water refers to that to which carbon dioxide has been added to create a sparkling product. Water coolers, accounting for 14% of the market by volume, are mainly available in public venues such as schools and offices. Similar to other types of beverages, water is consumed for a variety of reasons. Some of the health benefits of water consumption include improving energy levels, aiding weight loss – reducing obesity, removing toxins from the body and aiding digestion (BWCA, 2012). Despite the well documented health benefits, average annual consumption of bottled water in the UK stood at 33 litres per capita in 2010, significantly below the West European average of 115 litres (BSDA, 2011). This also compares unfavourably with the consumption of carbonated soft drinks of 103 l per person (see the previous section).

The UK bottled water industry, which accounts for 14% of the soft drinks sector (by volume), experienced fluctuation between growth and decline between 2004 and 2010. However, the UK market grew by 0.7% and 1.1% in volume and value, respectively between 2009 and 2010. The industry was also valued at around £1.4 billion in 2010 (BSDA, 2011). Of the total amount of bottled water consumed in the

UK in 2010, 93% was packaged in plastic bottles while 7% was packaged in glass and other unspecified packaging (BSDA, 2011) (see Figure 2-6). Similar to the carbonated soft drinks sub-sector, the bottled water sub-sector is dominated by global beverage manufacturing companies which are responsible for multiple product brands. Therefore it has not been possible to estimate how much the bottled water industry contributes to employment figures in the UK or the sector's contribution to national GDP.

As mentioned earlier, consumption of water has been linked to a host of positive health impacts. However, the study by Brown et al. (2007) showed that flavoured sparkling waters demonstrated dental erosive potential similar to or greater than that of pure orange juice, an established cause of dental erosion. Several studies (for example Dutty et al., 2003; Reddy et al., 2006; Sugiura-Ogasawara et al., 2005) have also suggested that phthalate compounds and bisphenol A – chemicals used in the manufacture of plastic bottles and the inside lining of cans – can interfere with human hormones thus negatively affecting growth, development and human health in general. However, the specific nature of the interactions between these substances and human systems is beyond the scope of this research.

The UK bottled water sector is estimated to be responsible for around 350,000 tonnes of CO_2 eq. emissions (NHC, 2010) or around 0.06% of the total UK GHG emissions[12]. Besides the carbon footprint of this sector, there is scant information on other environmental impacts. However, it can be inferred from consumption figures for bottled water that this sector is an important contributor to packaging waste streams in the UK.

[12] UK GHG emissions in 2010 are estimated at 582.4 million tonnes CO2 eq. (DECC, 2011).

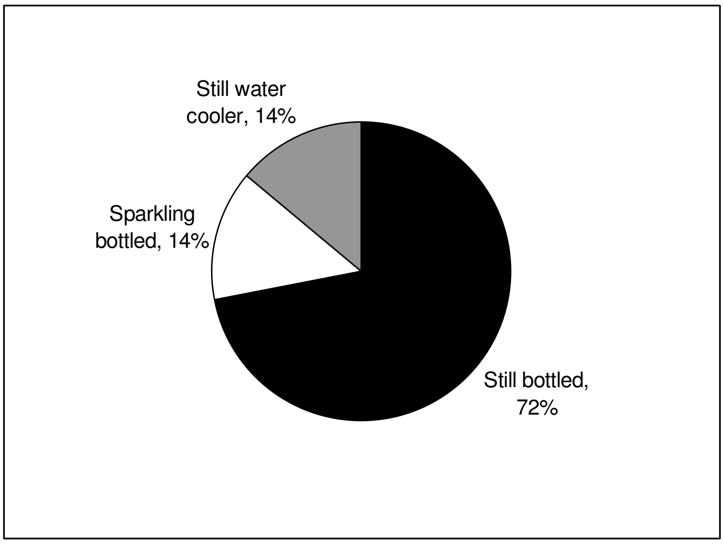

Figure 2-5 Bottled water categories by volume in the UK (BSDA, 2011)

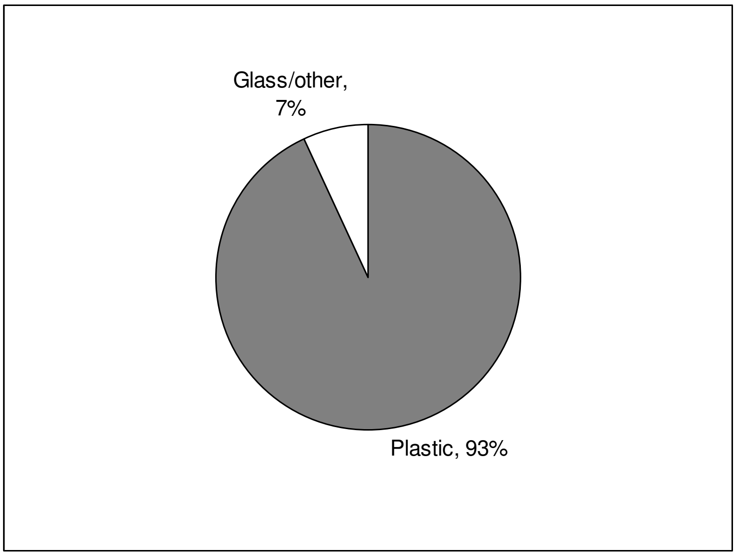

Figure 2-6 Bottled water packaging by volume in the UK (BSDA, 2011)

2.2.2 Alcoholic beverages

The UK alcoholic beverage sector is dominated by beer, wine and spirits, accounting for 43%, 28% and 20%, respectively of the sector by value (see Figure 2-7). As mentioned earlier (see section 2.2), alcoholic beverage consumption in the UK increased from 9.4 – 10.7 litres of pure alcohol (LPA) per adult between 1994 and 2009 (IAS, 2010). The increased total consumption has been attributed to increased consumption of 'non-traditional' drinks, notably wine, as well as reduction in the average age of onset of regular drinking (IAS, 2010). Other factors influencing alcohol consumption include price and income, licensing restrictions, taxation, advertising restrictions, social factors and underlying health requirements (Collis et al., 2010). In terms of distribution, it has been observed that there has been a long term increase in the amount of alcoholic drinks consumed at home (off-trade) rather than in entertainment venues such as bars and restaurants (on-trade) (IAS, 2010; Collis et al., 2010). The on-trade and take-home markets accounted for 46% and 54%, respectively in 2000, whereas in 2009, the on-trade and take-home markets accounted for 35% and 65%, respectively of total alcohol consumption in the UK (IAS, 2010). This trend of increasing consumption at home is mainly driven by the finding that alcoholic drinks purchased from off-licence premises cost on average one third of the cost of drinks purchased from on-trade outlets (IAS, 2010). It has also been estimated that UK households spend around £15 billion annually on consumption of alcoholic beverages, around 18% of total expenditure for food and drinks (ONS, 2010).

Regarding the economic impact of alcoholic beverages, the UK government was reported to have generated £9 billion from alcohol duties, around 2% of its total revenue from taxation in 2009-10 (Collis et al., 2010). Furthermore, the market was estimated to be worth £42 billion (retail selling price) in 2009 (Key Note, 2009). It has not been possible to obtain figures for the number of people employed in the UK alcoholic beverage sector.

Regarding the environmental and social impacts of alcoholic beverages, it has been estimated that alcohol consumption in the UK is responsible for 1.5% of the UK's total GHG emissions[13] (Garnett, 2007). It has also been estimated that consumption of alcoholic beverages contributed around 1.1 million tonnes of packaging waste to UK household waste streams (Jenkin, 2010). The trend of increasing consumption of alcoholic beverages through the off-trade channel suggests that the volume of packaging waste from this sector is set to increase beyond present levels. This also has significant implications for the issue of resource depletion. However, little is known about other environmental impacts. In relation to consumer health and other

[13] Although these figures are not directly comparable as in one case they represent the life cycle emissions in carbon equivalents (alcohol) and mainly direct emissions in carbon dioxide equivalents (total UK emissions), they provide an indication of the significance of the alcohol industry's contribution to UK emissions. Furthermore, this figure is likely to be underestimated due to the fact that the study considers only the three main categories of alcoholic drinks (beer wine and spirits) and packaging other than cans and glass bottles are not included in the study (Garnett, 2007).

social impacts, alcohol consumption has been causally linked to over 60 different medical conditions and around 4% of the global burden of disease (Room et al., 2005). Some of these include malignant neoplasms (cancers), neuropsychiatric disorders (e.g. depressive disorders, dependence and harmful use), cardiovascular disorders, gastrointestinal diseases and alcohol-induced injuries (e.g. accidents, drowning, poisoning, etc) (WHO, 2002; Rehm et al., 2003). More detail on the beer, wine and spirits sectors are given below.

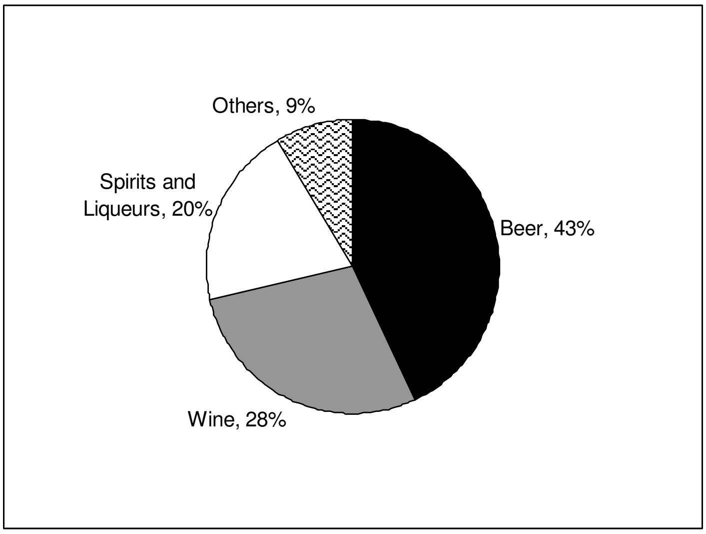

Figure 2-7 UK alcohol drinks sector by value (Key Note, 2009)

2.2.2.1 Beer

The beer sector, the largest alcoholic drinks sector in the UK, is made up of lagers and dark beers as shown in Figure 2-8. Lagers, which are light-coloured bottom-fermented beers with added carbon dioxide, are the most popular type of beer in the UK, while dark beers are also bottom-fermented and commonly referred to as ale, stout or bitter (Key Note, 2011). Total consumption of beer in the UK amounted to around 27 million barrels in 2010 (Key Note, 2011; BBPA, 2010). Of this amount, 53% and 47% were consumed in on-trade outlets (bars, restaurants and other entertainment venues) and at home (off-trade), respectively (BBPA, 2010). In terms of consumer penetration by type of packaging, canned and bottled beer accounted for 52% and 48% of the take-home market, respectively (see Figure 2-9) (Key Note, 2011). However, estimates show that overall consumption of beer in the UK has declined by around 5.6% since 2006. Factors influencing beer consumption in the UK are similar for other categories of alcoholic beverages as highlighted previously.

The total beer market was worth an estimated £17.8 billion (retail selling price) in 2010. In terms of its contribution to government revenues, the UK government was reported to have generated £3.2 billion from beer duties in 2009-10 (Collis et al., 2010). It has also been estimated that around 14,000 people were employed in the manufacture of beer in the UK in 2010 (BBPA, 2010). Socio-economic and other health impacts from the beer sector are similar to those for other alcoholic beverages as highlighted previously. In terms of environmental significance, Garnett (2007) estimates that beer accounts for around 65% of the GHG emissions from alcohol consumption in the UK. Together with cider, consumption of beer is also reported to account for around 470,000 tonnes of packaging waste from UK household waste streams (Jenkin, 2010). The issue of water consumption is also crucial for the brewing industry as evidenced by water footprint initiatives by global brewing companies such as SAB Miller and Anheuser Busch-Inbev. Furthermore, Foster et al. (2006) and Narayanaswamy et al. (2004) estimate that brewing requires between 4 and 7.8 litres of water per litre of beer.

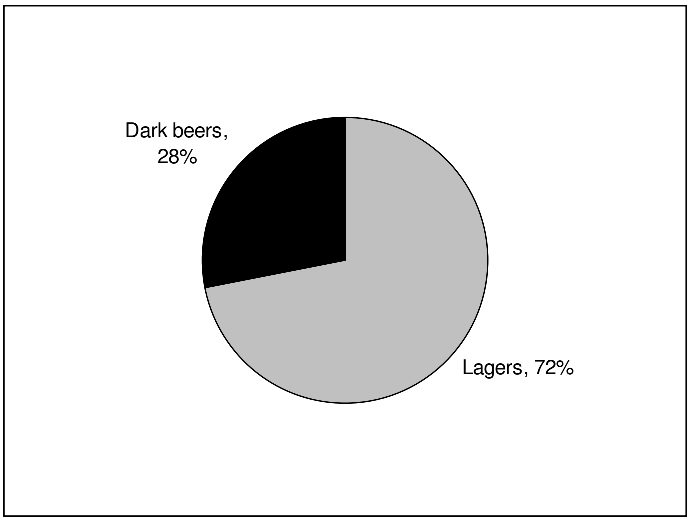

Figure 2-8 UK beer market by value (Key Note, 2011)

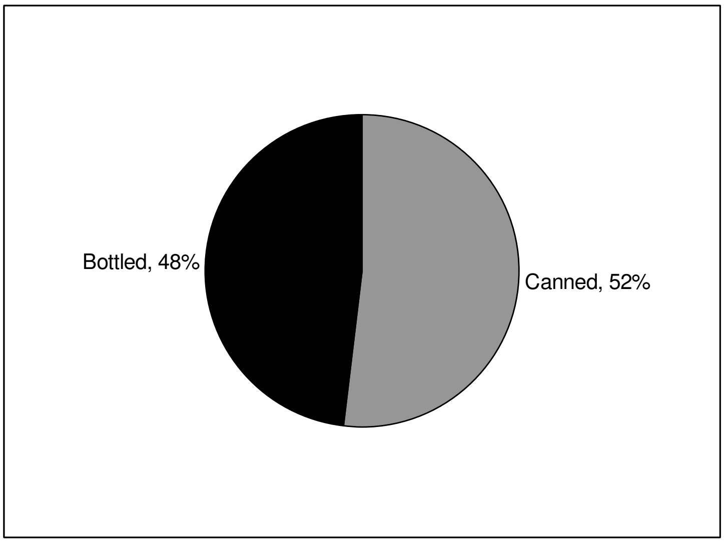

Figure 2-9 Penetration of beer by type of packaging (Key Note, 2011)

2.2.2.2 Wine

Only a relatively small quantity of wine is produced in the UK, therefore the UK wine sector is heavily dependent on imports. Australia and France represent the single largest sources, accounting for 17% and 13%, respectively of total UK wine imports (see Figure 2-10). In terms of actual volumes, 12.9 million hectolitres of wine[14] were released for sale in the UK from March 2010 to March 2011 (Key Note, 2011). Between 2006 and 2010, the market grew by 4% in terms of volume. However, it has been suggested that growth in the market is slowing, possibly due to saturation (Key Note, 2011). The off-trade represents the largest distribution channel, accounting for 67% of wine purchases in 2010. In 2009, this figure stood at 65% with this growth mainly attributed to lower average prices in supermarkets than in on-trade outlets (Key Note, 2011).

Regarding the economic impacts of the wine sector, the total wine market was worth an estimated £11.8 billion (retail selling price) in 2010. The market value also increased by 10.3% from 2006 to 2010 (Key Note, 2011). In terms of the sector's contribution to government revenue, the UK government was reported to have generated £2.9 billion from wine duties in 2009-10 (Collis et al., 2010). Employment

[14] This includes still wine under 15% alcohol by volume (ABV), sparkling wine and wine over 15% ABV but excludes wine made by alcoholic fermentation of any substance or the mixing of wine with any substance. Key Note (2011) sourced from Wine and Spirit Trade Association, from HMRC monthly statistical bulletin.

figures for domestic wine producers are not readily available although more significant levels of employment come from companies involved in importing and retail. The Wine and Spirit Trade Association (WSTA) boasts 340 members involved in the business of producing, importing, distributing and selling wines and spirits (Key Note, 2011).

Socio-economic and other health impacts from the wine sub-sector are similar to those for other alcoholic beverages as highlighted previously. In terms of environmental significance, Garnett (2007) estimates that wine accounts for around 27% of the GHG emissions from alcohol consumption in the UK. Consumption of table wine is also reported to account for around 559,000 tonnes of packaging waste from UK household waste streams (Jenkin, 2010).

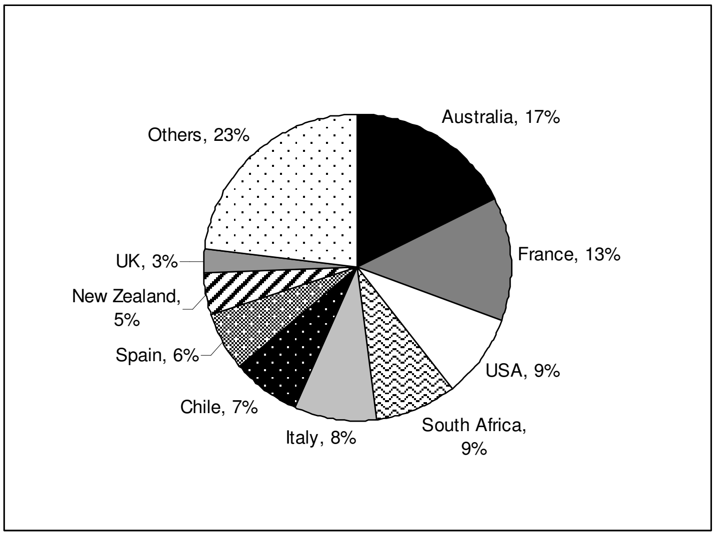

Figure 2-10 Wine purchased most often in the UK by country of origin (Key Note, 2011)

2.2.2.3 Spirits and liqueurs

Spirits and liqueurs are defined by their alcohol content which can ranges from 15% alcohol by volume (ABV) and above. Spirits typically have a higher ABV (above 37.5%) compared to liqueurs which range from 15% to 20% ABV (Key Note, 2010). As shown in Figure 2-11, vodka and Scotch whisky are the main sub sectors, accounting for 36% and 27%, respectively of the total UK spirits and liqueurs market (Key Note, 2010). In terms of domestic consumption, the most recent estimates show that around 25.8 million litres of Scotch whisky was released for consumption in 2009

(Scotch Whisky Association, 2009). However, total figures for all spirits and liqueurs are not available.

The total UK market for spirits and liqueurs was estimated to be worth £8.4 billion (retail selling price) in 2009 with vodka and Scotch whisky responsible for 36% and 27%, respectively (Key Note, 2010) (see Figure 2-11). Vodka was the best performing sub-sector, recording increase of 16.8% between 2005 and 2009. This growth has been attributed to its popularity among young consumers and versatility in cocktails. On the other hand, the Scotch whisky sub-sector witnessed a decline of 23.3% over the same period, along with varying degrees of decline in most of the other sub-sectors shown in Figure 2-11. It has been suggested that this decline may be due to consumers turning away from more traditional spirits and opting for more fashionable drinks, such as vodka (Key Note, 2010). Overall, the UK spirits and liqueurs market recorded a decline of 2.1% between 2005 and 2009 (Key Note, 2010). Notwithstanding the relatively poor domestic performance, the export market for Scotch whisky has recorded steady growth, increasing from £2.2 billion in 2004 to £3.4 billion in 2010. Scotch whisky also accounts for a quarter of UK food and drink exports (Scotch Whisky Association, 2010). Regarding other economic impacts, sales of spirits and liqueurs contributed £2.6 billion to the UK government revenue from taxes in 2010 (Collis et al., 2010) with Scotch whisky sales accounting for around £600 million. In terms of employment, figures show that only 5% of the 90 companies involved in the manufacture and distilling of spirits employed over 250 people in 2010, revealing that most of the companies had a small employee base (Key Note, 2010). However, it has been reported that over 10,000 people are employed in the Scotch whisky industry (Scotch Whisky Association, 2010).

Socio-economic and other health impacts from the spirits and liqueurs sector are similar to those for other alcoholic beverages as highlighted previously. With regard to environmental impacts from the sector, Garnett (2007) estimates that spirits account for around 7.1% of the GHG emissions from alcohol consumption in the UK. Consumption of spirits and liqueurs is also reported to account for around 115,000 tonnes of packaging waste from UK household waste streams (Jenkin, 2010).

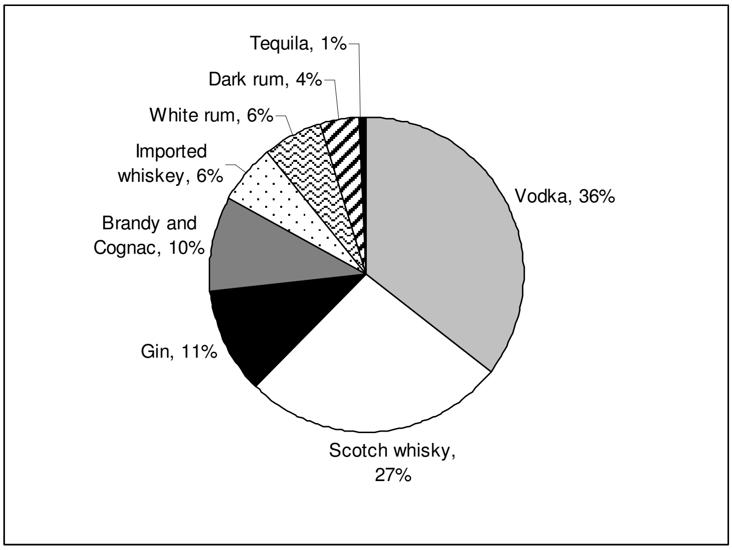

Figure 2-11 Spirits market by value (Key Note, 2010)

2.3 Sustainability initiatives in the UK beverage sector

In response to the environmental and socio-economic issues highlighted in the previous sections, industry and the government at the UK and EU levels as well as industry trade associations have proposed and implemented initiatives for sustainability improvements which impact on the beverage sector. These range from policy measures such as targets for emissions reductions to technological solutions. One of such sustainability initiatives is the Climate Change Act of 2008 which establishes an 80% minimum target for the reduction of net UK carbon emissions by 2050 relative to the 1990 baseline (Climate Change Act 2008). Other important policy instruments are the EU Packaging and Packaging Waste Directive (2004/12/EC) and the associated UK Producer Responsibility Obligations (Packaging Waste) Regulations of 2005 which aim to reduce the impact of packaging waste on the environment (Defra, 2005). The Courtauld Commitment, a voluntary agreement between the Waste and Resources Action Programme (WRAP) and several major UK beverage manufacturers and retailers, is also aimed at improving resource efficiency and reducing the environmental impacts of the UK grocery retail sector (WRAP, 2010). In the area of water stewardship, the Federation House Commitment (FHC), a responsibility commitment managed by WRAP and the FDF, has been implemented to help food and drink manufacturers reduce water usage within their companies (WRAP, 2011).

One of the key industry-driven initiatives is the Beverage Industry Environmental Roundtable (BIER), a partnership of leading global beverage companies, aimed at facilitating performance improvements in the areas of water conservation and resource protection, energy efficiency and climate mitigation (BIER, 2010). The Food and Drink Federation (FDF), the British Beer and Pub Association (BBPA) and the British Soft Drinks Association (BSDA) are also involved in various initiatives aimed at improving sustainability in the UK beverage sector. Regarding socio-economic aspects, the "Social Responsibility Standards for the Production and Sale of Alcoholic Drinks in the UK" is one of the key initiatives introduced with the aim of tackling consumer health and other social issues associated with alcohol consumption. Other initiatives include national campaigns to curb excessive drinking and resulting health impacts, provision of diet and low-calorie soft drinks, product labelling regarding nutritional information and strict advertising regulations regarding certain categories of beverage products (Department of Health, 2012; BSDA, 2011). Some of the relevant environmental and socio-economic sustainability initiatives are summarised in Table 2-1 and Table 2-2 respectively.

Table 2-1 Environmental sustainability initiatives

Environmental theme	Key sustainability driver	Performance initiative and goals
Climate change	Climate Change Act 2008	• Target for 67% reduction in GHG emissions from the soft drinks sector by 2020 compared to 1990 baseline (BBPA, 2011). • Target for 67% reduction in GHG emissions from the beer sector by 2020 compared to 1990 baseline (BSDA, 2011). • Publication of beverage sector guidance for GHG reporting (BIER, 2010).
Energy	Climate Change Act 2008	• To increase the use of renewable energy within the beer sector (BBPA, 2011). • To reduce energy consumption through more efficient lighting in factories (BSDA, 2011).

Water	Federation House Commitment - Food and drink industry target of 20% reduction in water use by 2020 compared to 2007 baseline.	• Target for 42% reduction in water use in the beer sector by 2020 compared to 1990 baseline (BBPA, 2011). • To reduce wastewater volumes from the soft drinks sector by using compressed air for rinsing bottles, installing water meters to monitor usage and rain water harvesting (BSDA, 2011). • Publication of guide for the application of water footprinting tools and methodologies (BIER, 2010).
Waste	EU Packaging and Packaging Waste Directive 2004/12/EC Courtauld Commitment 2010	• Beer sector commitment to reduce amount of waste to landfill year on year and increase reuse rates (BBPA, 2011). • Target for zero waste to landfill from soft drinks factories by 2015 (BSDA, 2011).
Packaging reduction, lightweighting and recycling	EU Packaging and Packaging Waste Directive 2004/12/EC Courtauld Commitment 2010	• To minimise the use of packaging without compromising the safety and quality of products (BBPA, 2011). • Aims to reduce the weight, increase recycling rates and the recycled content of packaging (BSDA, 2011).
Transport	Food and drink industry target to reduce the external impact of transport by 20% by 2020 compared to 2002 baseline.	• Aims to reduce the external impacts of transport by reducing journey distances, more efficient loading, energy-efficient driving techniques and alternative fuel and adoption of engine technologies (BSDA, 2011).

Table 2-2 Socio-economic sustainability initiatives

Socio-economic theme	Key sustainability driver	Performance initiative and goals
Consumer health and wellbeing	Social Responsibility Standards for the Production and Sale of Alcoholic Drinks in the UK. European Spirits Organisation (CEPS) Charter on Responsible Alcohol Consumption. Increasing awareness of health issues associated with beverage consumption.	• National and industry-driven campaigns aimed at curbing alcohol-related issues (Department of Health, 2012) • Television and radio advertising standards (ASA, 2010) • Provision of natural, functional, diet and low calorie soft drinks (BSDA, 2011) • Product labelling regarding nutritional information (BSDA, 2011)

Employment, workers, wages	UK Employment Act 2008 Global Reporting Initiative (GRI) G3 Guidelines	• Commitment to offering equal opportunities, training and apprenticeship opportunities (BSDA, 2011; AB Inbev, 2010)
Social responsibility and Community	Global Reporting Initiative (GRI) G3 Guidelines	• Sponsorship of community groups and activities, volunteering and donations (BSDA, 2011; AB Inbev, 2010)
Labour standards, Human rights	International Labour Organisation (ILO) Conventions United Nations Universal Declaration on Human Rights United Nations Global Compact (UNGC)	• Industry support of UN Global Compact which includes issues associated with human rights, forced labour, child labour, discrimination, etc (AB Inbev, 2010)

In addition to the drivers for sustainability initiatives as listed in Table 2-1 and Table 2-2 above, it has been suggested that some retailers and consumers are more likely to favour sustainably-manufactured products or those with "green" credentials (WRAP, 2007; Maibach et al., 2009). It has also been shown that sustainability initiatives are often linked with business benefits such as reduced supply chain disruptions, lower costs and business opportunities (CDP and Accenture, 2012). The implementation of these measures has resulted in environmental performance improvements in the areas of reduced material consumption and waste generation, as well as GHG emissions. For example, manufacturers of beverage packaging such as Ardagh Glass and O-I Glass have been involved in reducing the weight of glass bottles with annual savings ranging from 410 to 5,800 tonnes CO_2 eq. (WRAP, 2007b). In partnership with WRAP, Coca Cola Enterprises have also introduced new lightweight polyethylene terephthalate (PET) bottles for specific soft drink brands with annual savings of 700 tonnes of PET and 2,520 tonnes CO_2 eq. (WRAP, 2007b). In the beer sector, manufacturers such as Anheuser Busch Inbev, SAB Miller and Heineken UK have implemented packaging optimisation strategies resulting in significant material, GHG emissions and waste savings (WRAP, 2011).

With regard to socio-economic issues, companies in the beverage sector are involved in various initiatives in the areas of consumer health and general wellbeing, employment and labour standards, human rights and general social responsibility. Corporate social responsibility reports from trade association and companies in the beverage sector suggest that significant progress has been made in tackling the socio-economic issues highlighted.

2.4 Summary

The overview of the UK beverage sector presented in this chapter has highlighted its significance in terms of its economic, environmental and social aspects. As observed earlier, the UK beverage sector was valued at £58.3 billion (retail selling price) in 2009. The alcohol and soft drinks subsectors are the major components, accounting for 73% and 22%, respectively. The beverage sector is also reported to have grown by 2.9% between 2005 and 2009. This growth, fuelled by increasing beverage consumption, is expected to have a significant effect on the sustainability performance of the sector due to intensified production activities to meet this demand. Some of the impacts associated with the beverage sector include consumption of over 4 million tonnes of packaging annually, emission of significant amounts of GHG emissions, as well as consumer-related health impacts.

Various industry and government-driven sustainability initiatives have also been presented. Although these initiatives have helped to improve the performance of the beverage sector in the areas of GHG emissions, waste reduction and water consumption, the evidence suggests that other environmental impacts related to emissions to air, land and water have been largely overlooked. Furthermore, a number of environmental performance initiatives and achievements in the beverage sector are focused on activities within the scope of the beverage manufacturers' operations, as opposed to the whole supply chain. As mentioned previously, this study focuses on the life cycle impacts of beverages along the whole supply chains. Thus, only through an integrated assessment and balancing of these components will the beverage industry be able to achieve the goals of sustainable development. In response to this need, the subsequent chapter presents the life cycle methodology developed and used in this work.

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3 METHODOLOGY FOR SUSTAINABILITY ASSESSMENT OF THE UK BEVERAGE SECTOR

3.1 Introduction

In the preceding chapter, the environmental, economic and social issues associated with the UK beverage sector have been highlighted. The case has been argued that if the sector is to become more sustainable, it must be able to measure its progress towards sustainability. Therefore, appropriate methods and tools to analyse, assess, and manage all aspects of sustainability are of essential importance. As mentioned earlier, there are no integrated sustainability assessment frameworks for the beverage sector. Thus, this work proposes a methodology for evaluating the sustainability of the UK beverage sector, taking a life cycle perspective. This involves consideration of sustainability aspects of the beverage supply chain in its entirety – including production of agricultural inputs and other beverage ingredients, manufacture of the beverage and packaging, transport, retailing, as well as in-process and post-consumer waste management. Although the current work focuses on the UK beverage sector, the methodology is generic and can be applied to this sector in other countries. The following sections describe the sustainability assessment methodology developed and used in this work. The methodology is applied to five different types of beverage as detailed in Chapters 4 – 8, after which a sustainability assessment at the sectoral level is presented in Chapter 9.

3.2 The methodology

Figure 3-1 shows an overview of the methodology for sustainability assessment of the beverage sector, consisting of the following steps:

i. definition of the UK beverage system and system boundaries;
ii. identification of life cycle environmental, economic and social sustainability issues and indicators relevant for the beverage supply chains;
iii. sustainability assessment at the supply chain and sub-sectoral levels for selected beverages; and
iv. sustainability assessment at the sectoral level, using the results from the sub-sectoral assessment and market analysis.

These steps are described in more detail in the following sections.

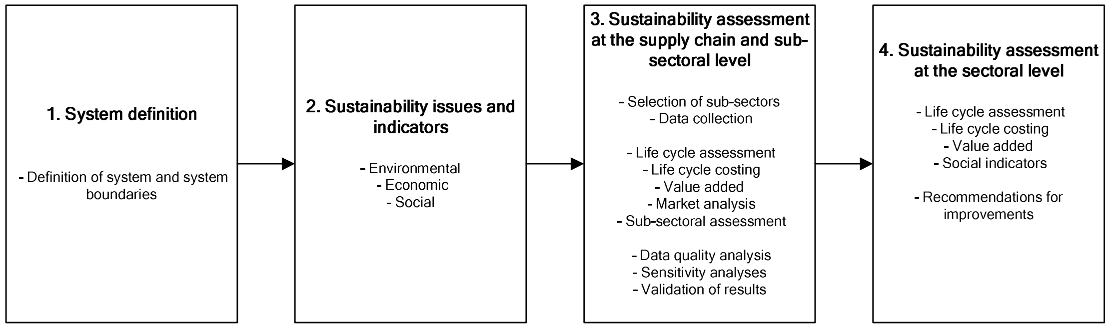

Figure 3-1 Overview of the sustainability assessment methodology

3.2.1 System definition and system boundaries

As illustrated in Figure 3-2, the beverage supply chain consists of the following life cycle stages which have been considered in this work:

i. raw materials/ingredients: this includes abstraction and supply of water from the public utility as well as production of agricultural inputs and other ingredients. The key agricultural raw materials in the beverage supply chains include cereals, sugar and wine grapes, while other ingredients include additives, preservatives, flavourings, colourings, etc.

ii. packaging: this life cycle stage involves production of primary and secondary packaging materials including glass and PET bottles, aluminium and steel cans, paper labels, HDPE bottle closures, LDPE stretch wrap and wood pallets;

iii. manufacturing: this stage comprises the use of energy (electricity and steam) in the manufacturing facility for activities including filling, capping and labelling of bottles and cans, blow moulding of PET preforms to make the bottles, and treatment of water used in the beverage formulation;

iv. storage and retail (refrigeration): this stage includes ambient and refrigerated storage along the supply chain, including at the retailer;

v. waste management: this stage involves recycling, landfilling, wastewater treatment and reuse of the different waste streams in the beverage supply chain; and

vi. transport: in this stage, transport of raw materials and packaging to the production facility, in-process waste to waste management, the packaged product to retail, and post-consumer waste to waste management are considered.

The use stage, consisting of refrigeration of the drink at the consumer, has not been considered due to lack of data. However, the waste packaging arising from this stage has been included in the analysis. More detail on the system boundaries and life cycle stages for each sub-sector considered in the current work can be found in the subsequent chapters.

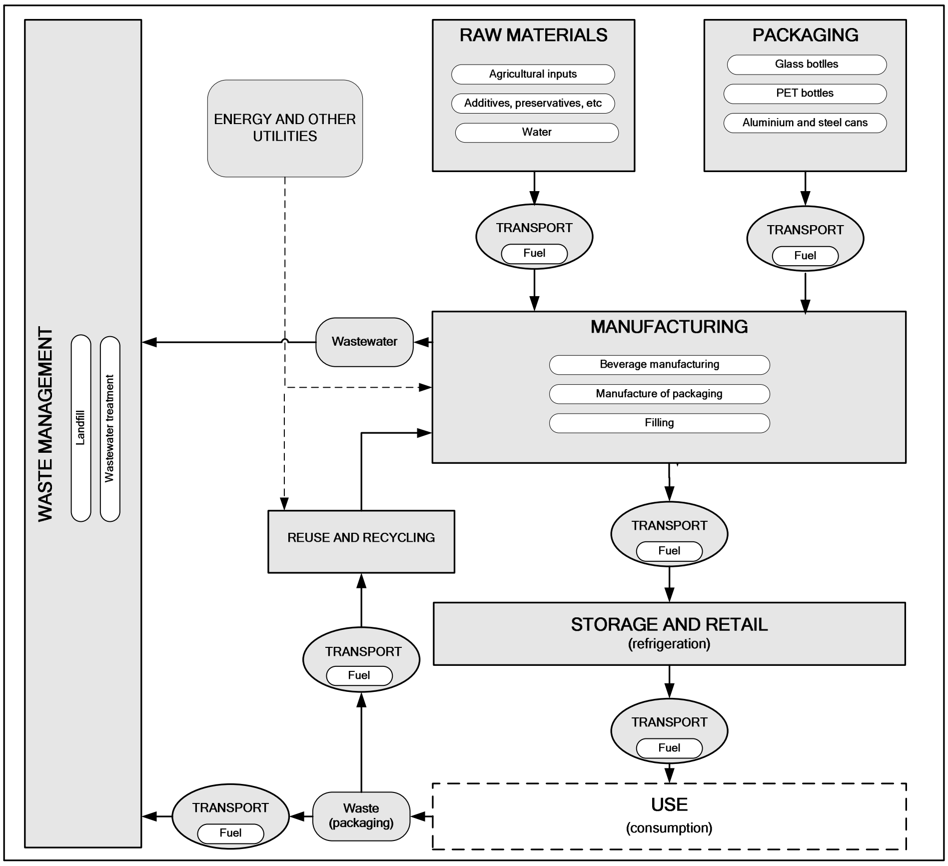

Figure 3-2 Generic life cycle of the beverage sector

3.2.2 Sustainability issues and indicators

The sustainability issues for the beverage sector, which form the basis of the sustainability assessment methodology, have been identified using information from industry trade associations (BSDA, 2009, 2011; BBPA, 2011; FDF, 2010; Scotch Whisky Association, 2010a, 2010b; NHC, 2010), government (Defra, 2005; WRAP, 2011), and other sources including Narayanaswamy et al. (2004), Foster et al. (2006)

and Garnett (2007). These issues have been discussed in the previous chapter and based on that, a number of sustainability indicators have been identified and considered in this work. The sustainability indicators are summarised in Table 3-1 and discussed subsequently. They are relevant to the sector's stakeholders, which include but are not limited to beverage producers and consumers, retailers and government.

Table 3-1 Sustainability issues and indicators for the beverage sector used in this work

Sustainability aspects	Sustainability issues and drivers	Sustainability indicators
Environmental	Climate change	Global warming[a]
	Resource depletion	Abiotic resource depletion[a] Primary energy demand Water demand
	Emissions to air, water and soil	Ozone depletion Acidification Eutrophication Human toxicity Freshwater aquatic ecotoxicity Marine aquatic ecotoxicity Terrestrial ecotoxicity Photochemical oxidant creation
Economic	Supply chain costs and profits	Life cycle costs Value added
Social	Sector-specific issues in the UK	Consumer health Human toxicity Government expenditure on treating consumer health issues Employment and wages
	Intergenerational issues	Global warming[a] Abiotic resource depletion[a]
	Issues based on international instruments and frameworks	Child labour Forced labour Wage assessment Excessive working time Freedom of association Collective bargaining Community infrastructure Indigenous rights Gender equality

[a] Environmental impacts with intergenerational consequences.

3.2.2.1 Environmental indicators

The environmental indicators considered in this work comprise the life cycle impacts normally considered in life cycle assessment (LCA), which has been used to estimate the environmental impacts from the UK beverage sector. LCA has been chosen as a tool since it enables the identification and quantification of the environmental impacts associated with the life cycle of a product, process or activity from extraction of raw materials to final disposal, which is congruent with the approach taken in this work. Other studies have also used LCA to estimate the environmental impacts of different beverages, including for beer (Talve, 2001; Narayanaswamy et al, 2004; Koroneos et al., 2005; Climate Conservancy, 2008), wine (Aranda et al., 2005; Colman and Päster, 2007; CIV, 2008a, 2008b), and bottled water (Jungbluth, 2006; Cerelia, 2008; SpA, 2010; Nestle, 2010; Coop, 2011). However, these studies cover other regions and only a handful of studies have been found that are UK specific but they have considered mainly greenhouse gas (GHG) emissions. These include the carbon footprint study of cola flavoured carbonated soft drinks (Coca Cola, 2010; Tesco, 2011), the contribution of the consumption of alcoholic beverages (beer, wine and spirits) to the UK GHG emissions (Garnett, 2007), and the impacts on GHG emissions of importing Australian wine to the UK (WRAP, 2007). A related study also considered the carbon footprint (global warming potential) of beverage packaging systems in the UK (Gujba and Azapagic, 2010). The study of Scotch whisky (Bell, 2000) is the only one that considered a range of different LCA impacts.

An overview of the LCA methodology can be found in Appendix 1, section A1.1. The CML 2001 method (Guinée et al., 2001) has been used for the analysis of the environmental impacts in this study. In addition to the impacts considered within the CML 2001 method, primary energy and water demand have also been assessed. The primary energy demand, estimated within LCA, assesses the consumption of renewable and non-renewable energy resources, while water demand quantifies the total water consumption in the systems under study. The environmental impacts are expressed in kg of the reference substance per 1,000 litres of beverage at the supply chain level. At the sub-sectoral and sectoral levels, the functional unit considers the total annual production and consumption of the beverages. More detail on the environmental impacts and how they are calculated is provided below.

Global warming

Global warming is arguably the most widely discussed environmental impact. It can be defined as the impact of anthropogenic emissions (such as CO_2, CH_4 and N_2O) on the absorption of heat radiation in the atmosphere (also referred to as radiative forcing) (Guinée et al., 2001). This may in turn, impact negatively on ecosystem viability and human health. The global warming potential (GWP) is expressed in kg of the reference substance, CO_2, and can be calculated using the equation (Azapagic, 2011):

$$\text{GWP} = \sum_{j=1}^{J} GWP_j B_j \tag{3.1}$$

where GWP_j is the global warming potential for substance j integrated over 100 years and B_j is the quantity of substance j emitted. GWP can also be assessed for shorter time horizons (20 and 50 years) providing an indication of the short term effects of GHGs on climate, or for longer periods (500 years), predicting the cumulative effect of GHGs on global climate (Azapagic, 2011).

Abiotic depletion

Depletion of abiotic natural mineral and energy resources including crude oil, coal, natural gas and metal ores, is one of the frequently discussed impact categories in LCA (Guinée et al, 2001). It is expressed in kg of the reference resource, Sb and can be calculated using the equation (Azapagic, 2011):

$$\text{ADP} = \sum_{j=1}^{J} ADP_j B_j \tag{3.2}$$

where ADP_j is the abiotic depletion potential or characterisation factor of resource j, and B_j is the quantity of resource j used.

Ozone depletion

This refers to the thinning of the stratospheric ozone layer due to anthropogenic emissions, causing an increase in the amount of solar UV-B radiation reaching the earth’s surface. This may in turn, impact negatively on human and animal health, ecosystem viability, biochemical cycles as well as materials (Guinée et al., 2001). Ozone depletion potential in the steady state is expressed in kg of CFC-11 equivalent and can be calculated thus (Azapagic, 2011):

$$\text{ODP} = \sum_{j=1}^{J} ODP_j B_j \tag{3.3}$$

where ODP_j is the steady-state ozone depletion potential for substance j, and B_j is the quantity of substance j emitted.

Acidification

Acidification refers to the adverse effects of acidifying pollutants (mainly SO_2, NO_X and NH_X) on soil, groundwater, surface waters, biological organisms, ecosystems and materials (e.g. buildings) (Guinée et al., 2001). Acidification potential is expressed in kg of SO_2 equivalent and can be calculated according to the equation (Azapagic, 2011):

$$\mathrm{AP} = \sum_{j=1}^{J} AP_j B_j \tag{3.4}$$

where AP_j is the acidification potential for substance j emitted to the air and B_j is the emission of substance j to air.

Eutrophication

Eutrophication refers to the negative impacts associated with high levels of macronutrients (mainly N and P) in both aquatic and terrestrial ecosystems. The impacts may include increased biomass production leading to lower oxygen levels in water bodies (Guinée et al., 2001). Eutrophication potential is expressed in units of PO_4 equivalent and is calculated using the equation (Azapagic, 2011):

$$\mathrm{EP} = \sum_{j=1}^{J} EP_j B_j \tag{3.5}$$

where EP_j represents the eutrophication potential of substance j emitted to air, water or soil, and B_j represents the emission of substance j to air, water or soil.

Human toxicity

This impact covers the impacts on human health of toxic substances emitted into air, water and soil. Although human toxicity has been estimated within LCA, it may be considered as a social indicator similar to the approach used by Dorini et al. (2010) and Stamford and Azapagic (2011). Human toxicity potential is expressed in kg of 1, 4-DCB equivalent and is calculated using the equation (Azapagic, 2011):

$$\mathrm{HTP} = \sum_{j=1}^{J} HTP_{jA} B_{jA} + \sum_{j=1}^{J} HTP_{jW} B_{jW} + \sum_{j=1}^{J} HTP_{jS} B_{jS} \tag{3.6}$$

where HTP_{jA}, HTP_{jW} *and* HTP_{jS} are toxicological classification factors for substances emitted to air, water and soil respectively, and B_{jA}, B_{jW} and B_{jS} represent the respective emissions of different toxic substances to air, water and soil.

Ecotoxicity

Ecotoxicity refers to the detrimental impacts on aquatic and terrestrial ecosystems of toxic substances, expressed in kg of 1,4-DCB equivalent. Ecotoxicity potential comprises five indicators ETP_n and can be calculated using the equation (Azapagic, 2011):

$$ETP_n = \sum_{j}^{J} \sum_{i=1}^{I} ETP_{i,j} B_{i,j} \tag{3.7}$$

where n (n = 1 – 5) represents freshwater aquatic ecotoxicity, marine aquatic ecotoxicity, freshwater sediment ecotoxicity, marine sediment ecotoxicity and terrestrial ecotoxicity respectively. $ETP_{i,j}$ respesents the ecotoxicity classification (characterisation) factor for substance j in the compartment i (air, water, soil) and $B_{i,j}$ represents the emission of substance j to compartment i.

Photochemical oxidant creation

Photochemical oxidant creation, also known as summer smog, refers to the formation of reactive chemical compounds (such as ozone and peroxyacetylnitrate) by the action of sunlight on certain air pollutants, which may have negative effects on human health, ecosystems and vegetation (Guinée et al., 2001). This impact is expressed in kg of the reference substance, C_2H_4 and calculated using the equation (Azapagic, 2011):

$$POCP = \sum_{j=1}^{J} POCP_j B_j \tag{3.8}$$

where $POCP_j$ represents the photochemical ozone creation potential of substance j emitted to air, water or soil, and B_j represents the quantity of substance j emitted.

3.2.2.2 Economic indicators

Two key life cycle economic indicators have been selected for consideration in this work: life cycle costs (LCC) and value added (VA) assessed at the supply chain, sub-sectoral and sectoral levels. LCC are calculated using life cycle costing as a tool and the latter are determined from the LCC results and the retail price of the beverages. The LCC and VA are discussed in more detail below.

Life cycle costs

The life cycle costing (LCC) methodology, developed by SETAC (Swarr et al., 2011) has been selected for use here as it is consistent with the LCA methodology. LCC represent the sum of all costs associated with the life cycle of a product that are directly covered by one or more actors in the product life cycle (Swarr et al., 2011). Similar to LCA, the conceptual framework for the environmental LCC methodology is based on the physical product life cycle, following the usual life cycle stages (Rebitzer and Hunkeler, 2003): production of materials or components, manufacturing, use and maintenance, and end-of-life management. In addition to these, research and development can also be considered (Swarr et al., 2011). Figure 3-3 illustrates the LCC concept.

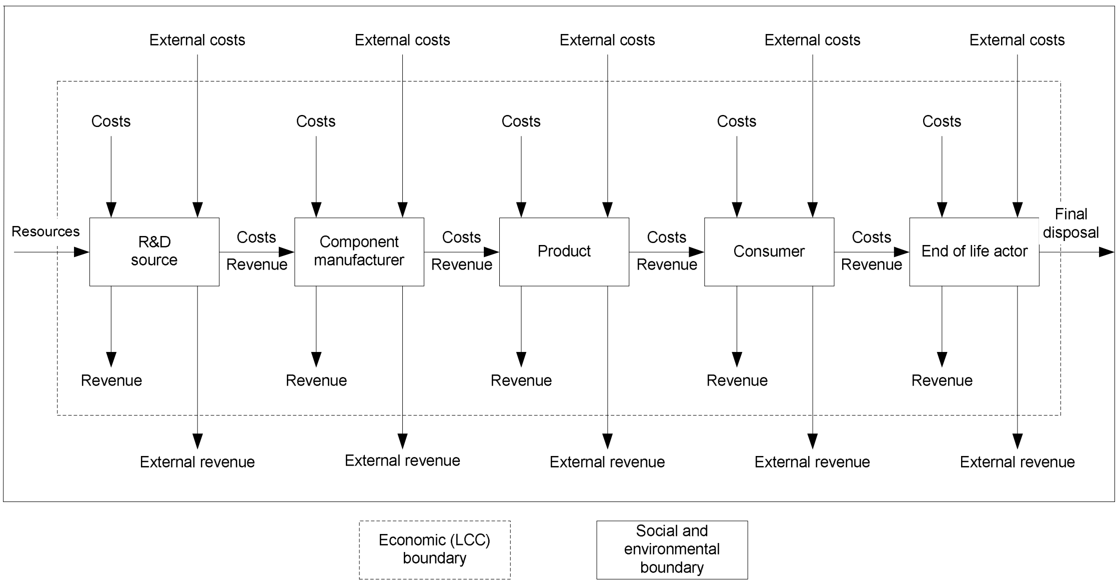

Figure 3-3 Conceptual framework of LCC (Rebitzer and Hunkeler, 2003 cited in Swarr et al., 2011)

Although no studies have been found in literature illustrating the application of the LCC methodology in the beverage sector, it has, in principle, been applied to a diverse range of other systems. Some of these applications include wastewater treatment (Rebitzer et al., 2003), bioethanol production (Luo et al., 2009), manufacture of capital goods (Hunkeler et al., 2008) and food production (Settani et al., 2010).

There is no universally agreed methodology for LCC. However, a code of practice (Swarr et al., 2011) has recently been published aimed at building consensus for an international standard that parallels the ISO 14040/44 LCA standards. The LCC methodology following this code and used in this work is detailed in Appendix A1.2. In summary, the study considers the perspective of the beverage manufacturer and consumer and the costs are calculated according to the following formula:

$$\text{LCC} = \sum (C_{RM} + C_P + C_M + C_{WM}) \qquad (3.9)$$

where C_{RM}, represents the costs of raw materials (ingredients), C_P is the cost of packaging, C_M is the manufacturing cost and C_{WM} represent the waste management costs. No capital assets are considered as they are already in place and due to their long life time, they are considered depreciated. The LCC is expressed in £ per 1,000 litres of beverage at the supply chain level. At the sub-sectoral and sectoral levels, the functional unit considers the total annual production and consumption of the beverages.

The study has been conducted as a steady state analysis in line with the SETAC code of practice for LCC (Swarr et al., 2011) which suggests that discounting can be neglected when the life time of the product is less than two years. While this may be a limitation, particularly given the volatile nature of cost data, this approach has been adopted in the current study in order to maintain consistency with the LCA which is traditionally steady state (Swarr et al., 2011) (see Appendix A1.2.2).

Value added

It has been observed that one of the primary aims of businesses is to create value added (VA) and through that wealth (Azapagic and Perdan, 2000). VA is a measure of financial performance which represents the net income of a company, calculated by deducting from the value of sales the costs of all raw materials and other bought-out purchases (Gilchrist, 1971 cited in Azapagic and Perdan, 2000). Other sustainability assessment and reporting frameworks, including that developed by Azapagic and Perdan (2000), IChemE Sustainability Metrics (IChemE, 2003) and the Global Reporting Initiative (GRI) Guidelines (GRI, 2010) have also used VA as an indicator of economic performance within the framework of sustainable development. In this work VA has been calculated according to the following formula:

$$VA = P_R - \sum(C_{RM} + C_P + C_M + C_{WM}) \quad (3.10)$$

where P_R represents the average retail price of the beverage in the major retail outlets in the UK, and C_{RM}, C_P, C_M and C_{WM} represent costs of raw materials, packaging materials, beverage manufacturing and waste management, respectively. Similar to the LCC, VA is expressed in £ per 1,000 litres of beverage at the supply chain level. At the sub-sectoral and sectoral levels, the functional unit considers the total annual production and consumption of the beverages.

3.2.2.3 Social indicators

The social indicators considered in this work have been selected taking into consideration the key social themes which are relevant to the UK beverage sector as well as those defined according to international social responsibility instruments and frameworks including the United Nations Global Compact (UN, 1999), Framework Indicators of Sustainable Development for Industry (Azapagic and Perdan, 2000), UNEP-SETAC Social LCA Methodology (Benoit and Mazijn, 2009), International Organisation for Standardisation ISO 26 000 Guidance on Social Responsibility (ISO, 2010) and the Global Reporting Initiative G3 Guidelines (GRI, 2011). In addition, health and intergenerational issues have been have been quantified at the sectoral level using the Human Toxicity Potential (HTP) and Global Warming Potential (GWP) respectively, estimated within LCA. Some of the indicators are quantitative (such as HTP and GWP), whilst others are qualitative (such as health and issues related to international instruments and frameworks). It should be noted that for some indicators, data are not available specifically for the drinks sector so that these issues are discussed in more general terms; this is for example the case with health, employment and some other qualitative indicators, as outlined below and discussed in more detail on Chapter 9 which deals with the social sustainability of the drinks sector.

Consumer health

As observed in Chapter 2 of this work, beverage consumption has been associated with a broad range of consumer health issues including obesity and alcoholism. A person is generally considered obese if they are overweight by 20 – 30% of their ideal body weight or has a Body Mass Index (BMI) of 30 or above (EIRIS, 2006). As it is difficult to obtain the data and estimate the contribution of the drinks sector to obesity and other health problems, this aspect is discussed in context of obesity incidence and related health issues in the UK. On the other hand, the incidence of alcoholism and related health problems can be linked directly with the drinks sector, as discussed in Chapter 9.

Human toxicity

Another health issue is human toxicity related to toxic emissions to air, land and water in the drinks supply chain. This has been assessed using the Human Toxicity Potential (HTP) estimated as part of LCA at the sectoral level. For more detail on the HTP, see section 3.2.2.1.

Government expenditure on treating consumer health issues

The financial implication of obesity, alcoholism and associated health conditions for the UK has been highlighted as a key socio-economic impact of the UK beverage sector in this work and other works (e.g. NHS, 2006, 2010). In this work, the significance of consumer health issues arising from alcohol misuse is expressed as the ratio of the annual government expenditure on treating the consequences of alcohol misuse to the annual government revenue from alcohol duties.

Employment and wages

These indicators aim to estimate the number of people employed in the UK beverage sector as well as the rate of pay for workers. However, due to a lack of data specific to the beverage sector, these issues are assessed in the context of the UK manufacturing sector.

Intergenerational issues (global warming and abiotic resource depletion)

Intergenerational issues have been assessed in this work using Global Warming Potential (GWP) and Abiotic Resource Depletion (ADP) estimated within LCA at the sectoral level. Global warming and abiotic resource depletion are considered as intergenerational issues due to the fact that they have long-term implications on the well-being of both present and future generations. The same approach has been applied by other researchers for other sectors, e.g. energy (Stamford and Azapagic, 2011). For more detail on the GWP and ADP, see section 3.2.2.1.

Child labour

Child labour is defined as work for children under the age of 18 that is mentally, physically, socially and/or morally harmful and that interferes with their education (Benoit et al., 2010). Risk of child labour can be specified at the country level according to the following criteria (SHDB, 2010):

- Low (<4%);
- Medium (>4-10%);
- High (>10-20%); and
- Very high (>20%).

The classification is based on evidence from relevant international organisations including UNICEF, US Department of Labour, International Labour Organisation (ILO) and the World Bank (Benoit et al., 2010). Based on the abovementioned criteria, the UK has been classified as 'Low risk' therefore; child labour is not an issue for the UK beverage sector. However, due to the global nature of the beverage supply chain, other countries (e.g. China, Colombia and India) in which unit processes are based may have a high risk of child labour. The methodology for assessing this and other social risks is detailed in section 3.4.3 of this work.

Forced labour

Forced labour refers to any work that is exacted from a person under the menace of a penalty and for which that person has not offered himself or herself willingly (UN Global Compact cited in Benoit et al., 2010). This indicator assesses the risk of forced labour at the country level based on the following qualitative criteria (SHDB, 2010)

- unknown: no data found;
- low: minimal evidence from available sources;
- medium: forced labour is indicated in one of the main sources; and
- high: forced labour is indicated in two or more of the main sources.

This classification is based on evidence from organisations including ILO, US Department of Labour, US Department of State, Amnesty International, Oxfam and the CIA World Fact Book (Benoit et al., 2010).

Wage assessment

This indicator assesses the potential of the average wage in the country of interest being below the non-poverty guideline of $2/day defined in the World Development Indicators Report (World Bank, 2009). The following risk characterisation factors have been defined based on the population living on less than $2/day (SHDB, 2010):

- Low (<2%);
- Medium (2-10%);
- High (10-50%); and
- Very high (>50%).

Excessive working time

Excessive working time is expressed in terms of percentage of the labour force working more than 48 hours/week. The following risk characterisation factors have been defined for this indicator (SHDB, 2010):

- Low (≤10%);
- Medium (10-25%);
- High (25-50%); and
- Very high (>50%).

The classification is based on evidence from organisations including ILO, the European Foundation for the Improvement of Living and Working Conditions, and the US Department of State (Benoit et al., 2010).

Freedom of association

This indicator assesses the risk to workers of not having freedom of association rights. The probability that a country does not offer provision for freedom of association rights has been characterised based on a subjective ranking of 1 – 4 where an average score of <1.5 indicates Low risk, <2.5 indicates Medium risk, <3.5 is High risk, and >3.5 indicates Very high risk that the laws are not enforced (SHDB, 2010). The classification is based on data from the International Trade Union Confederation (ITUC), World Trade Organisation (WTO), US Department of State and the Euro-Mediterranean Human Rights Network (Benoit et al., 2010).

Collective bargaining

This indicator assesses the risk to workers of not having collective bargaining rights. The probability that a country does not offer provision for collective bargaining rights has been characterised based on a subjective ranking of 1 – 4 where an average score of <1.5 indicates Low risk, <2.5 indicates Medium risk, <3.5 is High risk, and >3.5 indicates Very high risk (SHDB, 2010). The classification is based on data from the International Trade Union Confederation (ITUC), World Trade Organisation (WTO), US Department of State and the Euro-Mediterranean Human Rights Network (Benoit et al., 2010).

Access to community infrastructure (drinking water, sanitation and hospital beds)

Three indicators have been assessed within this impact category, namely risk of not having access to improved drinking water, risk of not having access to improved sanitation and risk of not having access to a hospital bed. Risk of not having access to improved drinking water has been characterised according to the percentage of the rural and urban population with access to improved drinking water sources (SHDB, 2010):

- Low risk (>91%);
- Medium risk (>87%);
- High risk (63%); and
- Very high risk (<63%).

Data for this characterisation have been sourced from the World Health Organisation (WHO) and the World Bank (Benoit et al., 2010).

Risk of not having access to improved sanitation has been characterised according to the percentage of the rural and urban population with access to improved sanitation facilities (SHDB, 2010):

- Low risk (≥77%);
- Medium risk (≥64%);
- High risk (≥45%); and
- Very high risk (≥0%).

Data for this characterisation have been sourced from the World Health Organisation (WHO) and the World Bank (Benoit et al., 2010).

Risk of not having access to a hospital bed has been characterised according to the following criteria (SHDB, 2010):

- High risk (<3 beds/1000 people);
- Medium risk (>3-5 beds/1000 people); and
- Low risk (>5 beds/1000 people).

Data for this characterisation have been sourced from various organisations including World Health Organisation (WHO), World Bank, European Observatory on Health Systems and Policies and OECD (Benoit et al., 2010).

Indigenous rights

This indicator assesses the risk of the country not adopting ILO Convention 169 and/or endorsing the UN Declaration on the Rights of Indigenous Peoples (UN, 2007). The following risk criteria have been adopted (SHDB, 2010):

- Low risk (countries with an indigenous population that have ratified C 169 and endorsed the UN Declaration);
- Medium risk (countries with an indigenous population that have not ratified C 169 and have abstained from signing the UN Declaration); and
- High risk (countries with an indigenous population that have not ratified C 169 and are against the UN Declaration).

Data for this characterisation have been obtained from various organisations including UNHCR, UNESDA, World Bank and ILO (Benoit et al., 2010).

Gender equality

This indicator assesses the overall risk of gender inequality at the country level. Characterisation of this indicator is based on a weighted average of different indices such as the Social Institutions and Gender Index (SIGI), Global Gender Gap (GGG), Gender Related Development Index (GDI) and Gender Empowerment Measure (GEM). The final risk characterisation is classified as (SHDB, 2010):

- Low (<1.3);
- Medium (1.3 – 2.3);
- High (2.3 – 3.3); and
- Very high (>3.3).

3.3 Sustainability assessment at the supply chain and sub-sectoral levels

This stage of the methodology applied in this study involves sustainability assessment at the supply chain and sub-sectoral levels and comprises the following steps (see Figure 3-1):

- selection of the sub-sectors to be studied in detail;
- data collection;
- estimation of the life cycle environmental impacts and costs using LCA and LCC, respectively;
- market analysis;
- extrapolation of the LCA and LCC results to the sub-sectoral level; and
- data quality analyses, sensitivity analyses and validation of the LCA results.

These steps are described below respectively. Note that the social sustainability is not considered at the supply chain and sub-sectoral levels to avoid duplication as most of the social issues are similar between the sub-sectors and at the sectoral level.

3.3.1 Selection of sub-sectors

The beverage sub-sectors considered in this work include carbonated soft drinks, beer, wine, bottled water and Scotch whisky. The selection of these sub-sectors is primarily driven by the need to estimate the sustainability impacts of the key sub-sectors that comprise the UK beverage sector (see Figure 2-1) – the sub-sectors included in this work comprise around 51% of the whole beverage sector by value. Secondly, selection of the sub-sectors assessed in this work has been driven by the availability of supply chain-specific primary production data.

3.3.2 Data collection

The data for the study have been collected from a variety of sources. Primary production data for the LCA have been sourced mainly from beverage manufacturers, including the amounts and origin of the raw materials and other ingredients, amounts of packaging materials, energy consumed during manufacturing, as well as transport modes and distances. All other data have been sourced from the CCaLC (2011), Ecoinvent (2010) and Gabi (PE, 2010) databases.

Cost data for the LCC have been obtained from generic published price data and spot market prices due to unavailability of supply chain-specific data. This may be a source of uncertainty and is acknowledged as a limitation of the current study. Furthermore, this imposes constraints on the level of detail with which the system can be analysed – for example, market prices for raw materials often include costs for labour, transport, taxes (e.g. VAT) and other hidden costs. Furthermore, due to the need to present the LCC results with a single reference currency, exchange rates corresponding to the time period of the analysis have been used. This is also acknowledged as a potential source of uncertainty in the study. More detail on the data sources for the specific sub-sectors can be found in the subsequent chapters.

3.3.3 LCA and LCC

GaBi v4.3 (PE, 2010) has been used to estimate the LCA impacts following the CML 2001 method (Guinée et al., 2001). The economic assessment comprises the estimation of material and energy procurement costs for each stage in the life cycle of the beverage supply chain. The LCC methodology has been described in more detail in Appendix A1.2. The results of the LCA and LCC studies at the supply chain and sub-sectoral levels can be found in Chapters 4 – 8.

3.3.4 Market analysis

This step of the methodology involves a study of the dynamics of the specialised markets within the UK beverage sector. Aaker (2001) outlined the following dimensions of a market analysis, including market size, projected growth, profitability, entry barriers, cost structure, distribution systems, trends and key success factors. The relevant dimensions of the market analysis applicable to this study include the total market size (in terms of value and sales volume), distribution channels (on and off-trade), types of packaging used and their penetration in the market, as well as the production volumes exported and consumed in the UK respectively. The specific market characteristics for the sub-sectors within the UK beverage sector have been discussed in the previous chapter.

3.3.5 Extrapolation of LCA and LCC results to the sub-sectoral level

Using the process-based LCA and LCC results for each beverage supply chain as well as the market analysis, the results have been extrapolated to the sub-sectoral level. This bottom-up approach is in contrast to the top-down, input-output approach (Hendrickson et al., 1998, 2006; Joshi, 2000) sometimes used in LCA for similar purposes. The top-down, input-output approach has several limitations, most notably its reliance on sector-level aggregated data which may not be representative of the specific sub-sectors which comprise an industrial sector. Other limitations include the fact that input-output models are not widely available for all countries, as well as the inclusion of only a limited number of environmental impacts. In this work, the extrapolation has been made using 1,000 litres of beverage as the basis considered at the supply chain level to the total annual production and consumption of beverages in the UK. The study by Amienyo et al. (2012) has also used this bottom-up approach to estimate the life cycle environmental impacts of the UK carbonated soft drinks sub-sector. However, the process-based, bottom-up approach applied in this work is not without limitations, most notably uncertainties arising from extrapolating the results of a single supply chain to the whole sub-sector. Suggestions for improving confidence in the results of this approach are given in the recommendations for future work as outlined in Chapter 10.

3.3.6 Data quality analyses

As data are often a source of uncertainties of study results, this step of the methodology involves an analysis of data quality. Some sources of uncertainty include variability in process data sourced from different databases, the imprecision to which the supply chain can be represented by these processes (based on temporal and geographic considerations) and assumptions made due to lack of specific data. While it is not always possible to quantify the uncertainties due to lack of data, they may be minimised by adhering to data quality rules which have been taken into account in the current study. For example, according to the PAS 2050 guidelines, the following data quality requirements should be considered when conducting an LCA study (BSI, 2011):

- time related coverage;
- geographical coverage;

- technology coverage;
- precision and accuracy;
- completeness;
- consistency;
- reproducibility; and
- sources of data (primary or secondary).

Taking the abovementioned criteria into account, a data quality analysis has been carried out following the CCaLC methodology (CCaLC, 2012) as an indication of the level of confidence in the results. This methodology is described below.

The criteria used in the data quality analysis methodology are summarised in Table 3-2 and Table 3-3. The data quality indicator was determined for each process (for the amounts of materials and energy, as well as the LCI data) based on the criteria given in Table 3-2.

Table 3-3 shows how the indicators have been aggregated to arrive at an overall Data Quality Indicator (DQI) – High, Medium or Low – for each process. For these purposes, each data quality criterion has been assigned a weight of importance on a scale of 1 – 10. For example, in the current study, age, geographical origin, source, completeness and reproducibility of data have been assigned arbitrary weights of 2, 1, 3, 2 and 2 respectively (see Table 3-3). Due to the subjective nature of the assigned weighting factors, these can be modified based on stakeholder preference or other criteria. Each data quality indicator has then been assigned (an arbitrary) maximum score for each criterion. For example, the High indicator has a score of 3, Medium has a score of 2 and Low has a score of 1 (see Table 3-3). Applying the weights of importance for each criterion and its maximum score for the respective quality indicators, the maximum score for each quality indicator is 30 for High, 20 for Medium and 10 for Low. Similar to the CCaLC methodology (CCaLC, 2012), the following score ranges have been adopted for the data quality assessment in the current study:

- Low data quality: score in the range of 1 – 10;
- Medium data quality: score in the range of 11 – 20; and
- High data quality: score in the range of 21 – 30.

As an illustration of the data quality assessment methodology, Table 3-3 shows a hypothetical process with an overall score of 19, indicating Medium data quality.

Table 3-2 Matrix of data quality indicators (CCaLC, 2011)

Data quality criteria Data	**Data quality indicators**		
	High	**Medium**	**Low**
Age of data	< 5 years	5 – 10 years	> 10 years
Geographical origin of data	Specific	Partly specific	Generic/average
Source of data	Measured and/or modelled based on specific data (e.g. company data or from suppliers)	Modelled using generic data from LCA databases; some data derived using expert knowledge	Mainly sourced from literature and/or estimated and/or derived using expert knowledge
Completeness of data	All inputs and outputs considered	Majority of relevant inputs and outputs considered	Some relevant inputs and outputs considered or known
Reproducibility, reliability and consistency of data	Completely reproducible/reliable/consistent	Partly reproducible/reliable/consistent	Not reproducible/reliable/not known

Table 3-3 Aggregating individual data quality indicators to arrive at an overall DQI for each process (CCaLC, 2011)

Data quality criteria	**Weighting for each criterion on a scale of 1 – 10**[a]	**High quality Max score for each criterion: 3**	**Medium quality Max score for each criterion: 2**	**Low quality Max score for each criterion: 1**	**Example data quality assessment**
Age	2	3	2	1	1 (Low)
Geographical origin	1	3	2	1	3 (High)
Source	3	3	2	1	2 (Medium)
Completeness	2	3	2	1	3 (High)
Reproducibility/reliability/consistency	2	3	2	1	1 (Low)
Maximum score		**30 (max score)** Overall score for High in the range: 21 – 30	**20 (max score)** Overall score for Medium in the range: 11 – 20	**10 (max score)** Overall score for Medium in the range: 1 – 10	**19 (overall score) Data quality indicator: Medium**

[a]The sum of all weights is 10.

It is important to note that the overall data quality depends on both the quality of the particular dataset used as well as on the confidence placed by the user on the quantity of materials or energy defined for each sub-system. For example, the quality of the background dataset and the related impact for a particular process may be High; however, the user may not be confident in the data related to the amount of that particular material/energy used in a specific sub-system so that the quality of his/her datum may be Medium. The data quality for this particular process will then be determined as Medium based on the approach for aggregation of data quality indicators for each process and sub-system given in Table 3-4.

Table 3-4 Aggregating the data quality indicators to arrive at an overall DQI for each sub-system or life cycle stage

DQI for LCI/LCC dataset	DQI for the amount entered by the user	Data quality of each sub-system of life cycle stage
High	High	High (3)
Medium	High	Medium (2)
Low	High	Medium (2)
High	Medium	Medium (2)
Medium	Medium	Medium (2)
Low	Medium	Low (1)
High	Low	Medium (2)
Medium	Low	Low (1)
Low	Low	Low (1)

Having calculated the data quality indicators for each sub-system, a weighted approach was then applied for assessing the overall data quality of the whole system based on the percentage contribution of each life cycle stage to the total environmental impacts. The overall data quality for the whole system has been calculated using the equation:

$$DQ_{LCA} = \sum_{n=1}^{N} I_n \left(\sum_{m=1}^{M} DQS_m\right) \quad (3.11)$$

where DQ_{LCA} represents the overall data quality of the system, I_n is the percentage contribution of each life cycle stage to the total environmental impact, and DQS_m is the data quality (1, 2 or 3) for sub-system *m*.

A similar approach has been adopted for the LCC data quality analysis taking into account the data quality requirements used in the LCA (age, geographical origin, source, completeness and reproducibility). The data quality for the LCC has been calculated using the equation:

$$DQ_{LCC} = \sum_{n=1}^{N} I_n \left(\sum_{m=1}^{M} DQS_m\right) \qquad (3.12)$$

where DQ_{LCC} represents the overall data quality of the system, I_n is the percentage contribution of each life cycle stage to the total life cycle costs, and DQS_m is the data quality (1, 2 or 3) for sub-system *m*.

3.3.7 Sensitivity analyses

Sensitivity analysis involves an assessment of the influence on the results of variations in process data, modelling choices and assumptions, as well as other variables in order to determine the robustness of the results (Guinée et al., 2001). Similar to data quality analyses, sensitivity analyses are aimed at addressing uncertainties in the LCA model. In this work, sensitivity analyses have been carried out by varying parameters within the key life cycle stages for the environmental impacts. For example, parameters including recycled content and weights of packaging, waste management options and transport modes have been varied to determine their influence on the final results. More detail on the sensitivity analyses and impact on the results can be found in the subsequent chapters.

3.3.8 Validation of LCA results

The validation of the findings of the LCA have been carried out by comparing the results obtained with values reported in peer reviewed, publicly available publications focusing on similar products. As observer earlier, only a handful of studies on the life cycle impacts of beverages in the UK have been found. Where studies from other countries have been used, the validation phase has involved identifying possible reasons for the differences in the results as well as trends in the relative impacts for different types of packaging used. More detail on the results of the validation can be found in Chapters 4 – 8.

3.4 Sustainability assessment at the sectoral level

The final stage of the methodology involves the following steps:

- extrapolation of the LCA and LCC results from the sub-sectoral to the sectoral level;
- an analysis of the social sustainability of the beverage sector; and
- recommendations for improvements.

3.4.1 Extrapolation of LCA and LCC results to the sectoral level

Using the LCA and LCC results for each sub-sector, the results have been extrapolated to the sectoral level. The impacts at the sectoral level consider the total annual production and consumption of five different types of beverage in the UK: carbonated soft drinks, beer, wine, bottled water and Scotch whisky. It is important to note that the sectoral impacts are not representative of the whole UK beverage sector as only five sub-sectors have been considered in this study. Furthermore, the sectoral impacts do not account for drinks consumed through the on-trade channel, as well as drinks consumed from dispensers and other unspecified types of packaging. More detail on the sectoral impacts is given in Chapter 9.

3.4.3 Social sustainability of the beverage sector

The assessment of social and socio-economic impacts in the UK beverage sector consists of three different approaches: a literature review of relevant issues in the UK, use of LCA to quantify human toxicity impacts and intergenerational issues such as GWP and ADP, as well as use of the Social Hotspots Database (SHDB) model (SHDB, 2010) to assess social risks in the host countries for the unit processes which comprise the UK beverage supply chain. The first set of social and socio-economic indicators (see Table 3-1), based on relevant social issues in the UK, is mainly available in the form of generic statistics and may not provide an accurate indication of the contribution of the beverage sector to these issues. For example, the problem of obesity can be attributed to other factors besides beverage consumption. However, it has not been possible to estimate the specific contribution of the beverage sector to this impact due to a lack of detailed data. Nevertheless, these are crucial social issues for the beverage sector and have been discussed accordingly. Data for these impacts have been sourced from literature.

Health issues have been have been quantified at the sectoral level using the Human Toxicity Potential (HTP) estimated within LCA. This is similar to the approach adopted by Dorini et al. (2010) and Stamford and Azapagic (2011). Within the context of sustainable development (WCED, 1987), intergenerational aspects are referred to as issues which affect current and future generations, therefore it is essential to address these issues (Azapagic and Perdan, 2011). Mitigation of climate change is as a key intergenerational issue. Therefore, GWP, also estimated within LCA, has been used in this work to assess this issue. Furthermore, depletion of abiotic resources is also an intergenerational issue which has been assessed through the ADP estimated as part of LCA. These two impacts have also been considered by Stamford and Azapagic (2011) in their assessment of energy systems.

The social indicators selected based on international instruments and frameworks have been analysed through the use of the Social Hotspot Database (SHDB) model with a focus on the countries in which production activities are based. This country-level Social Risk Assessment provides an overview of the social hotspots in the life cycle of the beverage sector. Social hotspots are defined as unit processes (production activities or companies) in the product life cycle that are at risk of or offer the opportunity to address social issues of concern (Benoit et al., 2010). The assessment involves the following steps:

- definition of the materials and utilities required for beverage production for the categories of beverage considered in this work, based on primary production data from the beverage manufacturers;
- definition of the unit processes in the life cycle of the beverage supply chain and identification of the countries in which these processes are based; and
- assessment of the level of risk in the countries identified in the first step in relation to the relevant social and socio-economic issues using the SHDB model.

Figure 3-4 shows the unit processes in the life cycle of the UK beverage sector and the countries in which the unit processes are based. It is important to note that it has only been possible to obtain the data on which the assessment is based as national level aggregates which do not provide sufficient detail to allocate the impacts among industrial sectors. This limitation has been noted. Notwithstanding, the assessment will help beverage manufacturers identify social risks and opportunities for improvement in their global supply chains.

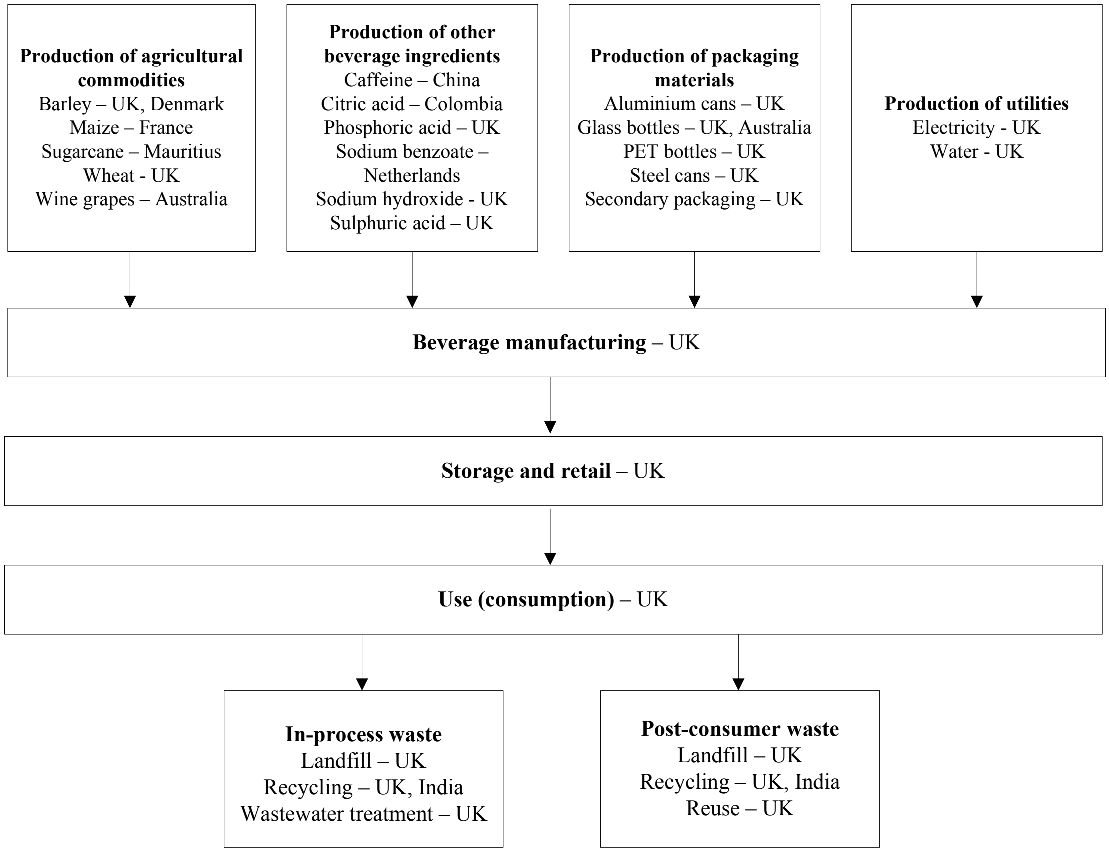

Figure 3-4 Production activities and geographic locations in the life cycle of the UK beverage sector

3.4.4 Recommendations for improvements

The final step of the sustainability assessment methodology involves making general recommendations with regard to methodological improvements, improving the quality of data used in the assessment and strategies for improving confidence in the results. This step also involves recommendations aimed at beverage manufacturers, beverage trade associations and the government mainly with regard to strategies for improving sustainability in the UK beverage sector.

The methodology developed and applied in this work for assessing the sustainability of the UK beverage sector is not without its limitations. These are mainly related to uncertainties in the methodology and the data used. A key limitation of the sustainability assessment at the sectoral level lies in extrapolating the LCA and LCC results of a single supply chain (which may not be fully representative of the sub-sector) to the sub-sectoral and sectoral levels.

3.5 Summary

In this chapter, the methodology developed for assessing the sustainability of the UK beverage sector has been presented. Following the guidelines for LCA and LCC presented in Appendix 1, Sections A1.1 and A1.2, these tools have been used for the assessment of environmental and economic aspects respectively. The functionality of the process-based LCA and LCC methodologies have been extended to assess the impacts at the sub-sectoral and sectoral levels using a bottom up approach which combines the results with market analysis. The assessment of social aspects has been carried out at the sectoral level using data from literature, quantitative indicators within LCA and the Social Hotspots Database (SHDB) model. The LCA and LCC results at the supply chain and sub-sectoral levels are presented in the subsequent chapters, after which the environmental, economic and social impacts at the sectoral level are presented in Chapter 9.

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4 LIFE CYCLE ASSESSMENT OF ENVIRONMENTAL AND ECONOMIC SUSTAINABILITY OF CARBONATED SOFT DRINKS

This chapter presents the life cycle assessment of environmental and economic sustainability of a carbonated soft drink. Life cycle assessment (LCA) is used to quantify the environmental impacts. The economic aspects are quantified using life cycle costing (LCC) and value added (VA) analysis. A similar analysis is also carried out for the whole carbonated soft drinks sector based on the results of LCA, LCC, VA and UK market analyses. The LCA results are discussed first followed by the LCC and VA analyses. Part of the section on LCA is based on the paper by Amienyo et al. (2012).

4.1 Life Cycle Assessment

This LCA study follows the LCA methodology as specified in the ISO 14040/44 standards (ISO, 2006a&b), starting with the goal and scope definition, followed by inventory, impact assessment and interpretation of results. Various sensitivity analyses are also performed as detailed further below.

4.1.1 Goal and scope of the LCA

This LCA case study has four main goals:

i. to estimate the environmental impacts and identify the hot spots in the life cycle of a carbonated drink produced and consumed in the UK;
ii. to analyse how the environmental impacts may be affected by the type and size of different packaging used in the UK: glass bottles (0.75 l), aluminium cans (0.33 l) and PET bottles (0.5 l and 2 l);
iii. to estimate the life cycle impacts from the whole carbonated soft drinks sector based on the findings from the first two goals of the case study and a UK market analysis; and
iv. to estimate the effect of potential improvement options on the life cycle environmental impacts.

For the first two goals of the study, the functional unit is based on 1,000 litres of carbonated drink. For the sectoral analysis, the functional unit considers total annual production and consumption of carbonated drinks in the UK.

The life cycle of the drink is shown in Figure 4-1. The system boundary is from 'cradle to grave', comprising the following life cycle stages:

- ***Raw materials (ingredients)***: water supply; cultivation of cane and processing of sugar; manufacture of citric acid, sodium benzoate and caffeine; carbon dioxide for carbonation (by-product from whisky production);
- ***Packaging***: production of primary packaging including glass bottles, aluminium cans, polyethylene terephthalate (PET) bottles, aluminium alloy and high density polyethylene (HDPE) caps, kraft paper and polypropylene (PP) labels; production of secondary packaging materials including corrugated board, kraft paper, low density polyethylene (LDPE) stretch wrap and wood pallets;
- ***Manufacturing and filling***: manufacture of the drink; blowing of PET preforms, washing of bottles, and filling of the drink in bottles and cans;
- ***Retail***: refrigerated storage of the drink at retailer (only as part of sensitivity analysis);
- ***Transport***: transport of ingredients, packaging materials and wastes along the life cycle; transport of the drink to retailer; and
- ***Waste management***: wastewater treatment, recycling and disposal of in-process and post-consumer waste.

The following activities are excluded from the system boundary due to lack of data:

- packaging of the ingredients;
- minor ingredients accounting for less than 1% (by weight) of the drink composition; and
- transport of consumers to purchase the drink and any storage at consumer.

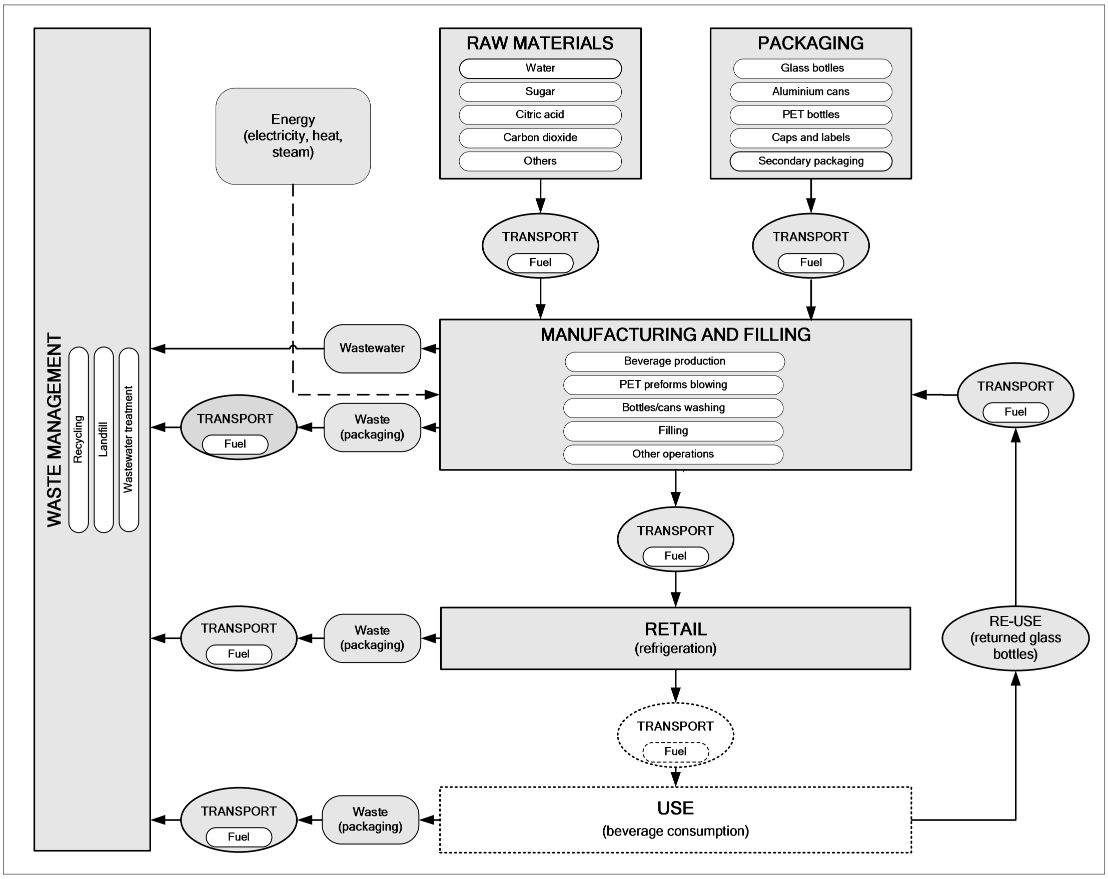

Figure 4-1 The life cycle of the carbonated drink

4.1.2 Inventory data and assumptions

Primary production data have been obtained from a drink manufacturer, including the amounts and origin of ingredients, the amounts of primary and secondary packaging materials, electrical energy consumed at the manufacturing and filling stage as well as transport modes and distances. All other data have been sourced from the CCaLC (2011), Ecoinvent (2010) and Gabi (PE, 2010) databases. More detail on the inventory data and their sources is provided below.

4.1.2.1 Raw materials (ingredients)

Most soft drinks consist of water, sugar, carbon dioxide (in the case of carbonated drinks), an acid and flavouring (BSDA, 2011; Key Note, 2011). As shown in Table 4-1, the composition of the carbonated drink considered here is similar, with the main ingredients being water and sugar, and small additions of citric acid, sodium benzoate and carbon dioxide. Raw sugar is sourced from Mauritius and transported to the manufacturing facility in the UK where it is refined. Citric acid is imported from

Colombia while sodium benzoate is imported from The Netherlands. Liquefied carbon dioxide is sourced from different production processes as ‘waste’.

Table 4-1 Drink ingredients

Ingredient	Drink composition (% by weight)	Source of LCI data
Water	85	Water UK (2009) Ecoinvent (2010)
Sugar	11	Ramjeawon (2004)
Citric acid	3	Bohnet et al. (2003), EC (2006)
Carbon dioxide	0.6	Ecoinvent (2010)
Sodium benzoate	0.02	Bohnet et al. (2003)
Colouring, flavouring and additive	0.02	n/a
TOTAL	100	

4.1.2.2 Packaging

The types of primary and secondary packaging are summarised in Table 4-2 and Table 4-3. The types of primary packaging selected for study – glass and PET bottles, and aluminium cans – are typically used for carbonated drinks in the UK. Glass bottles are assumed to contain 35% recycled content based on the UK situation for white container glass (British Glass, 2009). The tops are made from 84% aluminium alloy and 16% LDPE, using the data from the manufacturer. The body of aluminium cans is made of 48% recycled material while the can ends are from virgin aluminium (EAA, 2008). All components for the PET bottles are made from virgin plastics; tops are made of HDPE and labels of PP as specified by the manufacturer.

As shown in Table 4-3, the secondary packaging involves a variety of materials and systems, including corrugated-board top trays, LDPE bags and stretch wrap, wood pallets and their kraft paper labels, HDPE and cardboard boxes and plastic banding (straps).

Table 4-2 Components and weights of the primary packaging

Packaging type	Weight (kg /1000 l)	Source of LCI data
Glass bottle (0.75 l)	**800.1**	
Bottle body (35% recycled white glass)	797	Ecoinvent (2010)
Top (84% aluminium alloy and 16% LDPE)	2.05	Ecoinvent (2010), ELCD (2010), Gabi (PE, 2010)

Label (kraft paper)	1.04	Gabi (PE, 2010)
Aluminium can (0.33 l)	**39.5**	
Can body (48% recycled aluminium)	31.2	EAA (2008)
Can ends (100% virgin aluminium)	8.3	EAA (2008)
PET bottle (0.5 l)	**54.7**	
Bottle (virgin PET)	47.9	Ecoinvent (2010)
Top (virgin HDPE)	6.1	Ecoinvent (2010)
Label (virgin PP)	0.7	ELCD (2010), Gabi (PE, 2010)
PET bottle (2 l)	**23.5**	
Bottle (virgin PET)	21.4	Ecoinvent (2010)
Top (virgin HDPE)	1.5	Ecoinvent (2010)
Label (virgin PP)	0.6	ELCD (2010), Gabi (PE, 2010)

Table 4-3 Components and weights of the secondary packaging

Packaging type	Weight (kg/1000 l)	Source of LCI data
Glass bottle (0.75 l)		
Top tray (corrugated board)	1.78	Gabi (PE, 2010)
Secondary label (kraft paper)	2.0×10^{-3}	Gabi (PE, 2010)
Bag, stretch wrap (LDPE)	1.23	ELCD (2010), Gabi (PE, 2010)
Pallet (wood)	1.36×10^{-4}	Ecoinvent (2010)
Filled bottles to retail		
Stretch wrap (LDPE)	0.35	ELCD (2010), Gabi (PE, 2010)
Crate (HDPE)	2.18	PE (2009)
Pallet (wood)	0.62	Ecoinvent (2010)
Aluminium can (0.33 l)		
Banding (PET)	0.86	Ecoinvent (2010)
Stretch wrap (LDPE)	0.004	ELCD (2010), Gabi (PE, 2010)
Secondary label (kraft paper)	0.12	Ecoinvent (2008)
Filled cans to retail		
Stretch wrap (LDPE)	2.07	ELCD (2010), Gabi (PE, 2010)
Layer pads (cardboard)	8.27	Ecoinvent (2010)
Case and pallet labels (kraft paper)	0.07	Ecoinvent (2010)
Pallet (wood)	0.32	Ecoinvent (2010)
PET bottle (0.5 l)		
Box (HDPE)	6.06	Gabi (PE, 2010)
Corrugated board	0.60	Ecoinvent (2010)
LDPE bags	0.03	ELCD (2010), Gabi (PE, 2010)
Wood pallets	0.89	Ecoinvent (2010)
Filled bottles to retail		
Stretch wrap (LDPE)	3.39	ELCD (2010), Gabi (PE, 2010)
Layer pads (cardboard)	4.55	Ecoinvent (2010)
Case and pallet label (kraft paper)	0.19	Ecoinvent (2010)
Pallet (wood)	0.38	Ecoinvent (2010)

PET bottle (2 l)		
Box (HDPE)	3.59	Gabi (PE, 2010)
Corrugated board	0.17	Ecoinvent (2010)
LDPE bags	0.01	ELCD (2010), Gabi (PE, 2010)
Wood pallets	0.06	Ecoinvent (2010)
Filled bottles to retail		
Stretch wrap (LDPE)	2.15	ELCD (2010), Gabi (PE, 2010)
Layer pads (cardboard)	1.14	Ecoinvent (2010)
Case and pallet label (kraft paper)	0.05	Ecoinvent (2010)
Pallet (wood)	0.31	Ecoinvent (2010)

4.1.2.3 Manufacturing and filling

The ingredients are mixed together at the drinks manufacturing facility and the finished product is then packaged. Before mixing with other ingredients, the water undergoes a process of filtration and ultraviolet (UV) treatment. Table 4-4 shows the energy (electricity) used for these operations. The energy for filling and packaging of glass bottles includes de-palletising the bottles, washing of bottles and crates, filling, capping and labelling of the filled bottles, re-crating, re-palletising and stretch wrapping for delivery to retail. The energy for aluminium cans involves electricity for the air and belt conveyor systems, filling and sealing the filled cans. Finally, filling of the PET bottles comprises blow moulding of PET performs to make the bottles, washing and drying, capping, labelling and stretch wrapping, as well as use of the belt conveyor system.

Table 4-4 Electricity used in the manufacturing and filling stages

Stage	Energy (MJ/1000 l)	Source of LCI data
Drink manufacture	0.4	ELCD (2010) Gabi (PE, 2010)
Filling		
Glass bottle (0.75 l)	89.4	ELCD (2010), Gabi (PE, 2010)
Aluminium can (0.33 l)	86.7	ELCD (2010), Gabi (PE, 2010)
PET bottle (0.5 l)	105.9	ELCD (2010), Gabi (PE, 2010)
PET bottle (2 l)	41.3	ELCD (2010), Gabi (PE, 2010)

4.1.2.4 Retail (refrigeration)

As part of a sensitivity analysis, the global warming potential (GWP) of refrigerated drink storage at retailer has been considered. The 0.33 l aluminium cans and 0.5 l PET bottles have been selected for these analyses as these drink sizes are more commonly refrigerated at the retailer. As shown in Table 4-5 and Table 4-6, GWP from both electricity consumption and refrigerant leakage has been considered. The following assumptions have been made:

- the refrigerant is assumed to be R404 with GWP of 3860 kg CO_2 eq./kg (IPPC/TEAP, 2005);
- refrigerant charge is estimated at 3.5 kg/kW (van Baxter, 2002; IPPC/TEAP, 2005; DEFRA, 2007; Tassou et al., 2008);
- annual refrigerant leakage rate is assumed to be 15% (Tassou et al., 2008; US EPA, 2011);
- total display area of the refrigeration unit is 4.489 m^2 (BSI, 2005);
- the drink is refrigerated for one day (24 hours) before it is sold.

Table 4-5 Global warming potential from electricity consumption at retail

Drink packaged in:	Display cabinet type[a]	Electricity consumption[b] (kWh/m2.day)	Electricity consumption (kWh/m2.h)	Quantity of drink[c] (litres/m2 TDA[d])	Electricity consumption per volume of drink[e] (Wh/l.h)	GWP (g CO2 eq./l.day)
Aluminium cans	RVC3	13.8	0.58	70.6	8.2	120
PET bottles (0.5 l)	RVC3	13.8	0.58	106.9	5.4	72

[a]RVC3 = remote condensing unit, vertical, chilled
[b]Data from Tassou et al. (2008)
[c]Estimated by dividing the total drink volume in the display cabinet (316.8 litres for aluminium cans and 480 litres for PET; estimated by visual examination) by the cabinet TDA (4.489 m^2)
[d]TDA = total display area
[e]Estimated by dividing the cabinet electricity consumption by quantity of drink

Table 4-6 Global warming potential from refrigerant leakage

Drink packaged in:	Volume of drink chilled[a] (l/year)	Refrigerant losses per year[b] (g/l)	Refrigerant losses per l of drink[c] (g/l.day)	GWP[d] (g/l)
Aluminium cans	115,705	1050	0.0091	35.03
PET bottles (0.5 l)	175,200	1050	0.006	23.13

[a]Assuming 317 and 480 litres of Al cans and PET bottles in the cabinet, respectively; see note c for Table 4-5.
[b]Estimated by multiplying the annual refrigerant losses (15%) by the refrigerant charge (3.5 kg/kW) and the power of the refrigerated display unit (2 kW)
[c]Estimated by dividing the annual refrigerant losses by the total volume of drink cooled annually.

[d]Estimated by multiplying the refrigerant losses per litre of drink per day by the GWP emission factor for R404A of 3860 kg CO_2 eq./kg R404A.

4.1.2.5 Transport

The modes and distances for different parts of the drink system are listed in Table 4-7 – Table 4-9. Where no specific data have been available, a generic distance of 50 km has been used for post-consumer waste materials.

Table 4-7 Transport modes and distances for ingredients, packaging and packaged drink

Material	Mode	Country of origin	Distance (km)	Source of LCI data
Sugar	Rail freight Truck (40 t)	Mauritius	993 534	ELCD (2010), Gabi (PE, 2010) Gabi (PE, 2010)
Citric acid	Container ship Truck (40 t)	Colombia	9,154 378	ELCD (2010), Gabi (PE, 2010) Gabi (PE, 2010)
Caffeine	Container ship Truck (40 t)	China	19,953 441	ELCD (2010), Gabi (PE, 2010) Gabi (PE, 2010)
Sodium benzoate	Container ship Truck (40 t)	The Netherlands	362 441	ELCD (2010), Gabi (PE, 2010) Gabi (PE, 2010)
Glass bottles	Truck (40 t)	UK	39	Gabi (PE, 2010)
Aluminium caps	Bulk carrier	UK	378	Gabi (PE, 2010)
Labels	Truck (40 t)	UK	19	Gabi (PE, 2010)
Aluminium cans	Truck (40 t)	UK	604	Gabi (PE, 2010)
Aluminium can ends	Truck (40 t)	UK	604	Gabi (PE, 2010)
PET preform	Truck (40 t)	UK	398	Gabi (PE, 2010)
HDPE tops	Truck (40 t)	UK	355	Gabi (PE, 2010)
PP labels	Truck (40 t)	UK	205	Gabi (PE, 2010)
Filled bottles/cans to retail	Truck (40 t)	UK	10	Gabi (PE, 2010)

Table 4-8 Transport modes and distances for in-process waste[a]

Material	Mode	Destination country	Distance (km)
Kraft paper labels to landfill	Truck (40 t)	UK	33
Aluminium caps to recycling	Truck (40 t)	UK	20
Plastic wastes to recycling	Truck (40 t)	UK	29

Corrugated board to recycling	Truck (40 t)	UK	32
Glass bottles to recycling	Truck (40 t)	UK	80
Waste PP labels to landfill	Truck (40 t)	UK	20
LDPE bags to landfill	Truck (40 t)	UK	20
Waste aluminium cans to recycling	Bulk carrier	India	11,500
Waste aluminium can ends to recycling	Bulk carrier	India	11,500
Waste PET bottles to recycling	Truck (40 t)	UK	20
Waste HDPE caps to recycling	Truck (40 t)	UK	20
Plastic wastes from the aluminium system (LDPE and PET) to recycling	Truck (40 t)	UK	20
Paperboard waste from the PET systems to recycling	Truck (40 t)	UK	32

[a]All LCI data from the Gabi database (PE, 2010)

Table 4-9 Transport modes and distances for re-used bottles, retail and post-consumer waste[a]

Material	Mode	Destination country	Distance (km)
Glass bottles (retail to manufacturer)[b]	Truck (40 t)	UK	12
Glass bottles to landfill	Truck (40 t)	UK	20
Aluminium alloy caps to landfill	Truck (40 t)	UK	20
Kraft paper labels to landfill	Truck (40 t)	UK	20
Aluminium cans to recycling	Bulk carrier	India	11,500
Aluminium can ends to recycling	Bulk carrier	India	11,500
LDPE stretch wrap to recycling	Truck (40 t)	UK	50
LDPE stretch wrap to landfill	Truck (40 t)	UK	50
Cardboard to recycling (from the aluminium can system)	Truck (40 t)	UK	50
Cardboard to landfill (from the aluminium system)	Truck (40 t)	UK	50
PET to recycling	Truck (40 t)	UK	50
PP to recycling	Truck (40 t)	UK	50
LDPE to recycling	Truck (40 t)	UK	50
PET to landfill	Truck (40 t)	UK	50
PP to landfill	Truck (40 t)	UK	50
LDPE to landfill	Truck (40 t)	UK	50
Cardboard to recycling (from the PET systems)	Truck (40 t)	UK	50
Cardboard from landfill (from the PET systems)	Truck (40 t)	UK	50

[a]All LCI data from the Gabi database (PE, 2010)
[b]This applies to return of reusable bottles from retail to the manufacturer

4.1.2.6 Waste management

As indicated in Table 4-10, all relevant waste streams have been considered, including in-process packaging and drink waste as well as post-consumer waste packaging. In-process packaging waste includes bottles and cans broken during the delivery to the manufacturing site and in the filling process. This waste amounts to 0.60% of the total amount of glass bottles, 0.63% for the aluminium cans, and 1.05% and 0.68% for the 0.5 l and 2 l PET bottles, respectively. For both the in-process and post-consumer waste, the average UK waste management options have been assumed (see Table 4-10).

The system has been credited for the avoided burdens from recycling of waste packaging. Note that glass bottles in the UK are used only once and then recycled. However, as part of the sensitivity analysis, reuse of glass bottles has also been considered. The reuse takes into account activities such as transportation, de-palletising, de-crating, de-capping, washing and inspecting the bottles during each reuse cycle. Effluents from the manufacturing stage, consisting of drink wasted during the filling (0.3% wt.) and waste water from washing the bottles and cans, are sent to wastewater treatment.

Table 4-10 Waste management options[a]

Waste	Amount (kg/1000 l)[b]	Waste management[c]	Source of data for waste management options
Glass bottle (0.75 l)			
Glass	518	65% landfilled	British Glass (2009)
Aluminium	0.83	48% recycled	EAA (2008)
	0.89	52% landfilled	Defra (2009)
Plastics	0.98	24% recycled	Defra (2009)
	3.11	76% landfilled	Defra (2009)
Paper/cardboard	2.26	80% recycled	Defra (2009)
	0.57	20% landfilled	Defra (2009)
Wastewater	40.55	Wastewater treatment	Manufacturer

Aluminium can (0.33 l) Aluminium Plastics Paper/cardboard	 3.98 20.54 0.71 2.22 6.77 1.69	 48% recycled 52% landfilled 24% recycled 76% landfilled 80% recycled 20% landfilled	 EAA (2008) Defra (2009) Defra (2009) Defra (2009) Defra (2009) Defra (2009)
PET bottle (0.5 l) Plastics Paper/cardboard Wastewater	 13.95 44.17 4.27 1.07 267.50	 24% recycled 76% landfilled 80% recycled 20% landfilled Wastewater treatment	 Defra (2009) Defra (2009) Defra (2009) Defra (2009) Manufacturer
PET bottle (2 l) Plastics Paper/cardboard Wastewater	 6.16 19.50 1.09 0.27 66.88	 24% recycled 76% landfilled 80% recycled 20% landfilled Wastewater treatment	 Defra (2009) Defra (2009) Defra (2009) Defra (2009) Manufacturer
Waste drink and wastewater from drink manufacturing	591	Wastewater treatment	Manufacturer

[a]All LCI data from the Gabi database (PE, 2010)
[b]Includes in-process and post-consumer waste; estimated based on the data provided by the drink manufacturer and post-consumer waste arising
[c]Where recycled materials have been used in the input packaging materials; the system has not been credited for recycling to avoid double counting.

4.1.2.7 Data quality

Using the data quality assessment approach presented in Chapter 3 of this work, the LCA data quality has been assessed for the carbonated soft drink. The overall LCA data quality for the carbonated soft drink system has been estimated as 'High' for the different packaging systems considered in this work. More detail on the data quality assessment is provided in Appendix 3, section A3.1.

4.1.3 Impact assessment and interpretation

The Gabi 4.3 LCA software has been used to model the system. The CML 2001 (Guinee et al., 2001) impacts characterisation method has been used to estimate the environmental impacts. In addition to the impacts included in the CML method, two further aspects are considered: primary energy demand and water demand. The global warming potential is discussed first followed by the other environmental impacts.

4.1.3.1 Global warming potential (GWP)

The results for the GWP of the carbonated drink are given in Figure 4-2. The highest GWP (555 kg CO_2 eq. per 1,000 l of drink) is found for the glass packaging and the lowest (151 kg CO_2 eq.) for the 2 litre PET bottle. The drink in the aluminium can has the GWP of 312 kg CO_2 eq. and in the 0.5 litre PET bottle 293 kg CO_2 eq. per functional unit. The GWP of the unpackaged drink, consisting of impacts from production and mixing of the ingredients in the production facility, is estimated as 40.1 kg CO_2 eq. per 1,000 l of drink.

As can also be seen from Figure 4-2, packaging is the major hot spot contributing between 49% (2 l PET bottle) and 79% (aluminium can) of the total GWP. This is mainly (90%) due to the primary packaging. It is interesting to note that the GWP for the 0.5 l PET bottle is higher than that of the 2 l PET bottle by a factor of 2 due to the higher amount of packaging material needed per functional unit.

The contribution to GWP from the manufacturing stage ranges between 4% (aluminium cans) and 13% (0.5 l PET bottles) and is mainly due to the electricity consumption. The ingredients contribute from 7% for the glass to 26% for the 2 l PET bottle. About 71% of this is from sugar production as shown in Figure 4-3. This is due to the production of fertilisers and pesticides as well as cultivation and harvesting of sugar cane. The second largest contribution (16%) to the GWP of the ingredients is from carbon dioxide despite its accounting for just 0.6% of the drink's composition and having no impacts from its manufacture since it is produced as 'waste'; however, the energy used for its purification and liquefaction before being added to the drink adds to the impacts. It should also be noted that, due to the assumed biogenic origin of carbon dioxide, its release during the use stage is excluded from the total GWP. Assuming, on the other hand, that the carbon dioxide is of fossil origin, its release during consumption would add around 6 kg CO_2 eq. or 1 – 4% to the total GWP of the drink.

Citric acid contributes 11% to the GWP of the ingredients mainly due to the energy intensive manufacture. Although water constitutes the majority of the drink, its contribution is negligible (1%). The contribution of waste management is similar to that of the manufacturing stage, ranging from 2% to 12% for the aluminium can and 0.5 l PET bottle, respectively. The contribution of transport is small (up to 2.7%) despite the significant transportation distances involved.

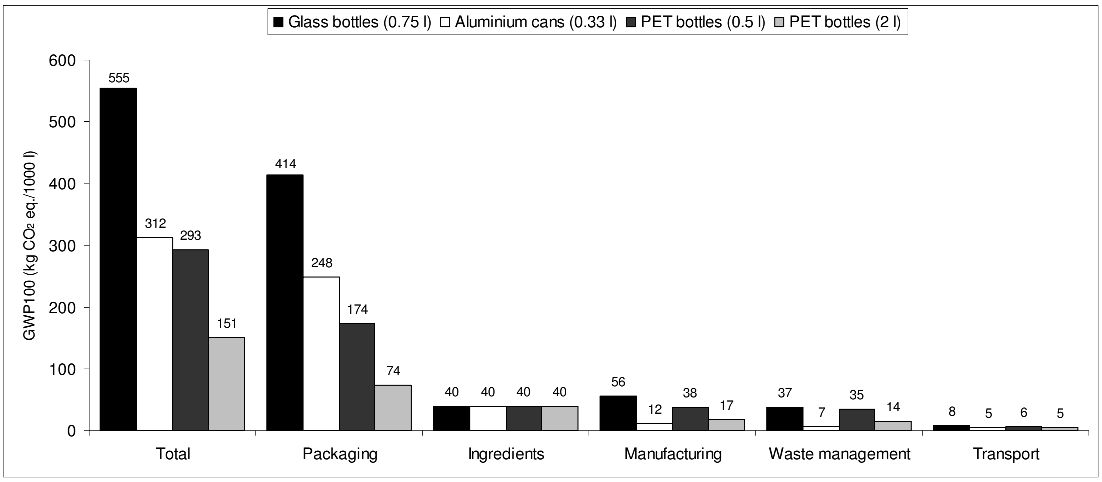

Figure 4-2 Global warming potential of the carbonated drink for different types of packaging also showing the contribution of different life cycle stages

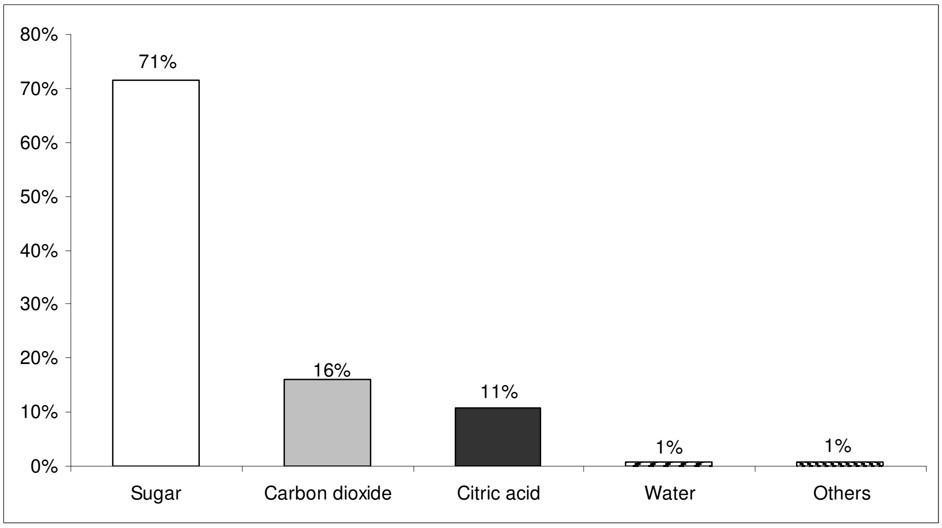

Figure 4-3 Contribution of the drink ingredients to the global warming potential

4.1.3.2 Impact on GWP of refrigerated storage at retailer

A further analysis has been carried out to assess the impact of refrigerated storage at the retail stage on the GWP. As previously mentioned, only the cans and 0.5 l PET bottles are considered as the drink sizes that are often refrigerated by retailers in the UK. The results are presented in Figure 4-4. As shown, the refrigerated storage adds 33% to the total GWP of the drink for the cans and 24.5% for the PET bottles. After packaging, this is now the second largest contributor to the total GWP of the drink. The results also indicate that 75% of the total GWP from refrigeration is contributed by electricity used to power the refrigerator and 25% by refrigerant leakage (see Table 4-5 and Table 4-6). Furthermore, it can be noticed that the GWP of the refrigerated drink in the PET bottle is 20% higher than the GWP of the drink in the aluminium can stored at ambient temperature (see Figure 4-2 and Figure 4-4). Therefore, refrigerated storage at retailer should be avoided, particularly as carbonated drinks are not perishable goods. However, consumer perception and taste preference are the main drivers for refrigeration and most retailers would be reluctant to discontinue this practice.

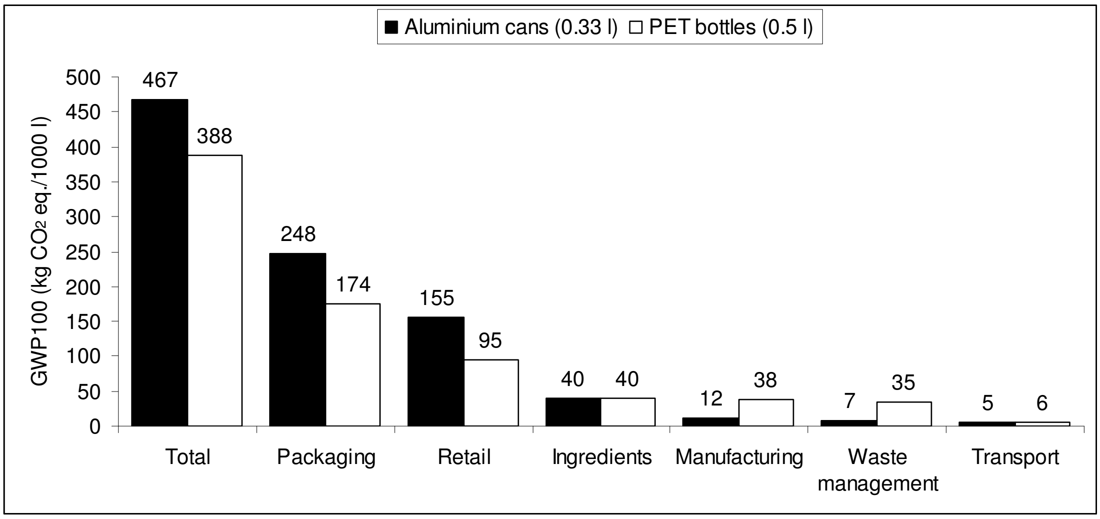

Figure 4-4 Contribution to global warming of retail (refrigerated storage) of the drink for aluminium cans (0.33 l) PET bottles (0.5 l)
[The retail stage comprises electricity use and refrigerant leakage from refrigerated storage as calculated in Table 4-5 and Table 4-6]

4.1.3.3 Impact on GWP of glass bottle reuse

Given that the glass bottle is the most significant contributor to the GWP in the carbonated drink system, reusing the bottles has been considered to find out how the impact would change. The results in Figure 4-5 show that by reusing the bottle only once, the GWP would be reduced by about 40%. Further savings in GWP can be achieved by increasing the number of reuses, although the benefits are not as significant after the second reuse and they gradually level out after about eight reuses. This is due to the increasing significance of the transport and cleaning – the benefit from the avoidance of the bottle manufacture is shared between the different numbers of reuses, diminishing the influence of the bottle manufacture on the total GWP as the rate of reuse increases.

The results also indicate that if the glass bottles were reused three times, the GWP of the drink packaged in glass bottles would be comparable to that packaged in aluminium cans and 0.5 l PET bottles. Thus, there is a clear case for reusing bottles between 1-5 times, depending on the economics of the operation.

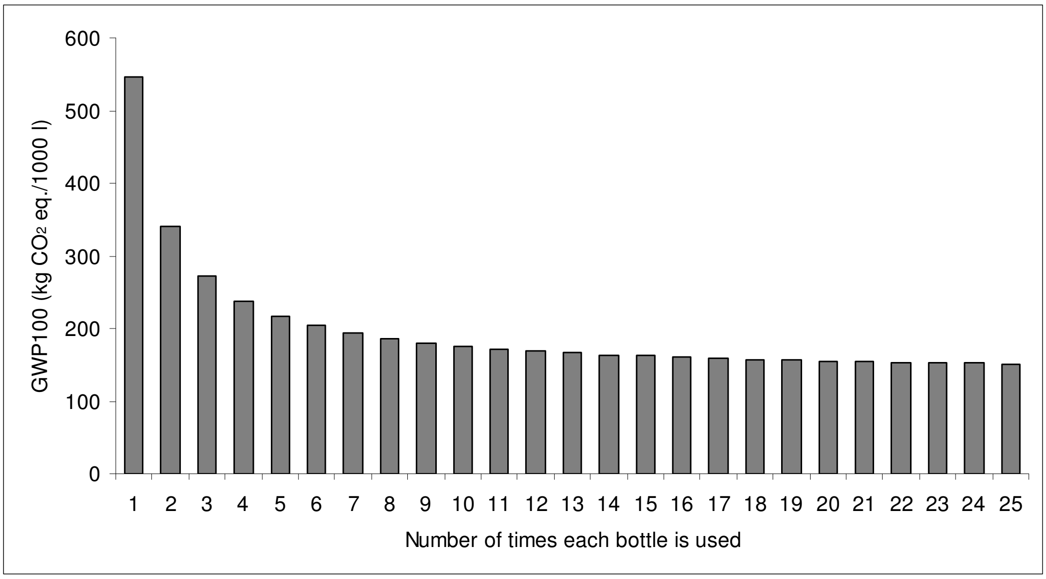

Figure 4-5 Effect of glass bottle reuse on global warming potential

4.1.3.4 Impact on GWP of PET recycling rates

PET recycling rates in the UK are increasing although it is still not clear how much of PET resin is recycled back into the bottles. One study suggested that 37% of PET bottles were collected in the UK in 2009 (Welle, 2011), but it does not provide data on how much of that was actually recycled and particularly back into PET bottles. In the absence of the actual data, several (hypothetical) recycling rates are considered here, using the 0.5 litre bottle as an example. As shown in Figure 4-6, considering only the PET bottles in isolation of the rest of the drink system, shows that increasing the recycling rates from 15%-100% reduces GWP by up to 40% per kg of PET bottles. Similar, although slightly lower, savings are achieved at the systems level. For example, increasing the PET bottles recycling rate to 40% from the UK average for plastics recycling of 24% (as assumed in this study; see), reduces the GWP for the whole system by 32%, from 293 to 197 kg CO_2 eq./1,000 l (Figure 4-7). Increasing recycling to 60% reduces the total GWP of the carbonated drink by half compared to the current recycling rate. This would also mean that the GWP of the drink in the 0.5 l PET bottle would be half that of the aluminium can (152 kg CO_2 eq./1,000 l compared to 312 kg CO_2 eq./1,000 l, respectively; see Figure 4-2 and Figure 4-7). At the same time, glass bottles would have to be reused around 20 times to make them comparable to a 60% recycled PET bottle. Therefore, the benefits of PET recycling are clear and should be increased as much as economically feasible (and subject to the law on recycling of food packaging).

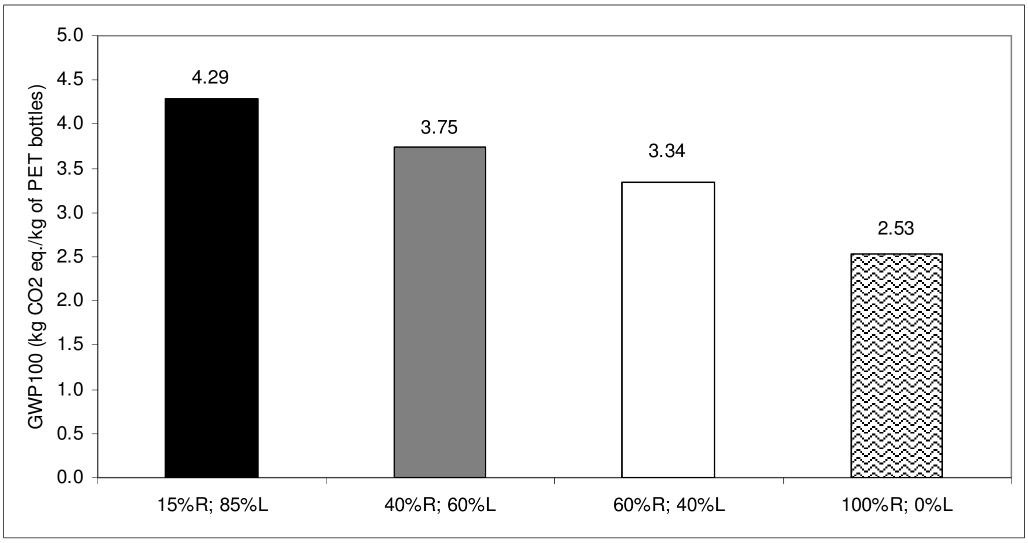

Figure 4-6 The effect of different PET recycling rates on global warming potential per kg of 0.5 litre PET bottles (CCaLC, 2011)
(R-recycling; L-landfill)

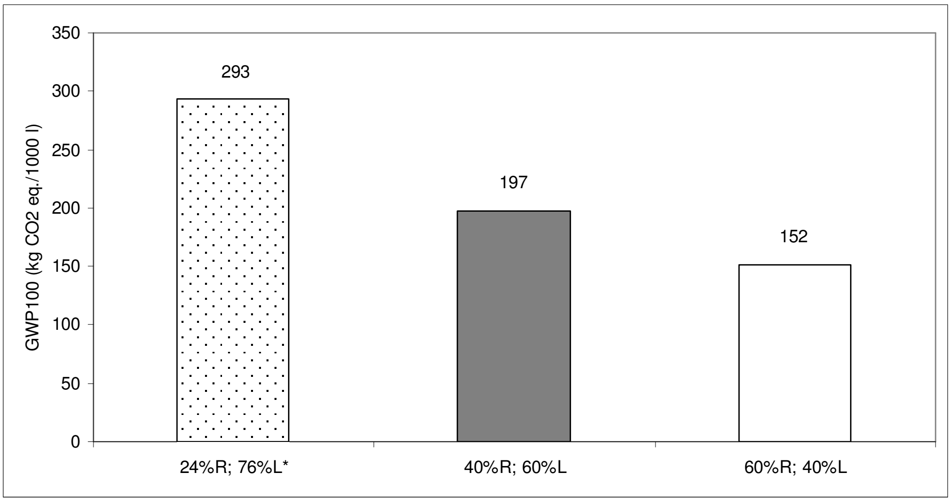

Figure 4-7 The effect of different PET recycling rates on global warming potential (for the whole system with 0.5 litre bottles)

(R-recycling; L-landfill; *Reference scenario as used in the rest of the paper: 24%R & 76%L for all plastic waste (in-process and post-consumer, see Table 4-10); 40%R; 60%L and 60%R & 40%L: all post-consumer waste (bottle, tops and labels) and 24%R & 76%L for all in-process plastic waste)

4.1.3.5 Impact on GWP of cane and beet sugar

Having identified sugar as the main contributor to GWP from the drink ingredients, the environmental performance of sugar production from the 2 major plant sources – sugarcane and sugar beet – has been estimated as part of the sensitivity analysis. Sugar production from sugarcane accounts for 80% of global sugar production with sugar beet accounting for the remaining 20% (EC, 2012). Although the EU is the world's largest producer of beet sugar, it is also a principal importer of raw cane sugar for refining (EC, 2012) as typified by the current case study. The sensitivity analysis has considered the cradle-to-gate impact of beet sugar produced in the UK and Switzerland with cane sugar produced in Mauritius and Brazil. The results shown in Figure 4-8, suggest that, on average, cane sugar has a lower GWP than beet sugar. However, various studies and LCI databases including Klenk et al. (2012), Renouf et al. (2008) and Ecoinvent (2010) have estimated the environmental impacts of cane and beet sugar with wide variations in the results obtained. The study by Klenk et al. (2012), based on around 30 published carbon footprint studies, estimated that the carbon footprint of beet sugar in the EU was in the range of 242 – 771 g CO_2 eq. per kg of sugar, which was found to be similar, if not lower than that of cane sugar imported and refined in the EU. However, the results were determined to be sensitive to methodological choices (system boundaries and allocation methods) therefore, difficult to compare the actual performance of the sugar products (Klenk et al., 2012).

Renouf et al. (2008), in a comparative LCA study of Australian sugarcane, US corn and UK sugar beet for sugar production, found sugarcane to be more advantageous with regard to GHG emissions. Considering sugar production in isolation of the rest of the drink system, sourcing beet sugar from the UK or Switzerland increases the GWP by around 125% or 90%, respectively per kg of sugar compared to the current operations. On the contrary, sourcing cane sugar from Brazil reduces GWP by around 23% per kg of sugar compared to the current operations. At the systems level, this translates to GWP savings ranging from 1.2% (glass bottle) to 4.3% (2 l PET).

Although the results of the abovementioned studies suggest that cane sugar is more advantageous than beet sugar with regard to GWP, other environmental, economic and social aspects have to be taken into account when sourcing ingredients for beverage production.

Figure 4-15 shows the relative environmental performance (with regard to other environmental indicators) of beet sugar from Switzerland and cane sugar from Brazil.

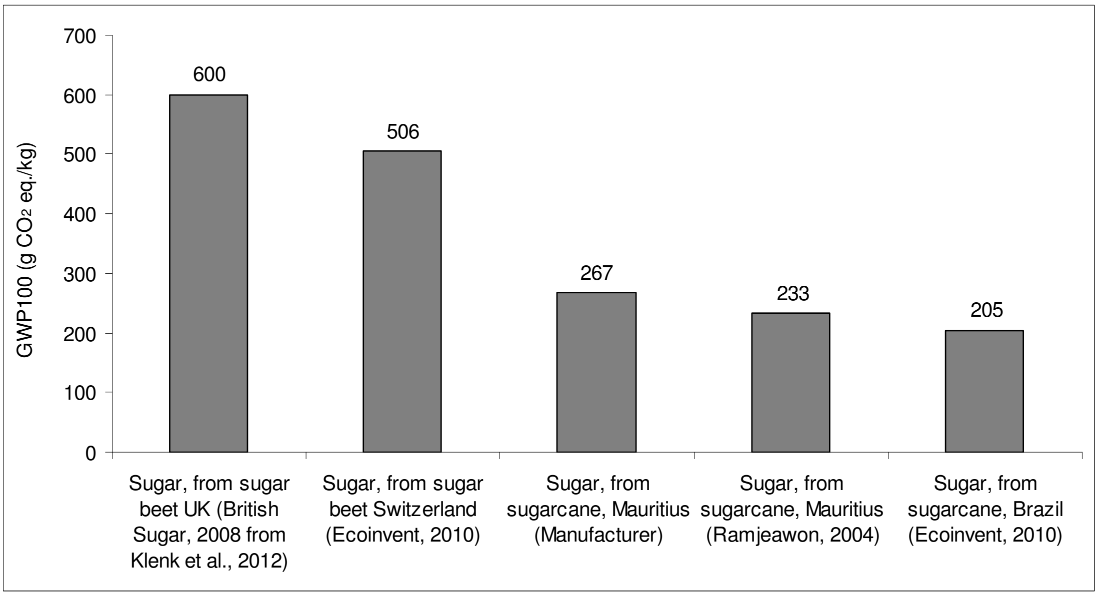

Figure 4-8 The effect of cane and beet sugar on global warming potential per kg of sugar

[The GWP values shown take into account all processes from cradle to the factory gate.]

4.1.3.6 Comparison of GWP results with other studies

The results for GWP have been compared in Figure 4-9 to the other two studies of carbonated soft drinks (Tesco, 2011; Coca Cola, 2010). As can be seen, the results differ as the drinks considered are probably quite different (the composition of the other two drinks is not disclosed). The results will also be influenced by the types and sources of ingredients, background energy mixes, transport distances, waste management options and whether the drinks are refrigerated, neither of which is known for the Tesco or Coca Cola studies. Therefore, in the absence of detail on the other two studies, it is not possible to identify the actual reasons for the difference in the results. With respect to refrigeration, it is also not clear from those studies whether refrigerated storage was considered, but if so, then the results are more comparable to the current study.

Nevertheless, all three studies show the same trends with respect to the types of packaging. For example, for all drink types, GWP is higher for aluminium cans than for PET bottles. Moreover, similar to the current study, the Coca Cola and Tesco studies show that packaging is the main contributor to GWP, accounting for between 30 – 70% of the total GWP.

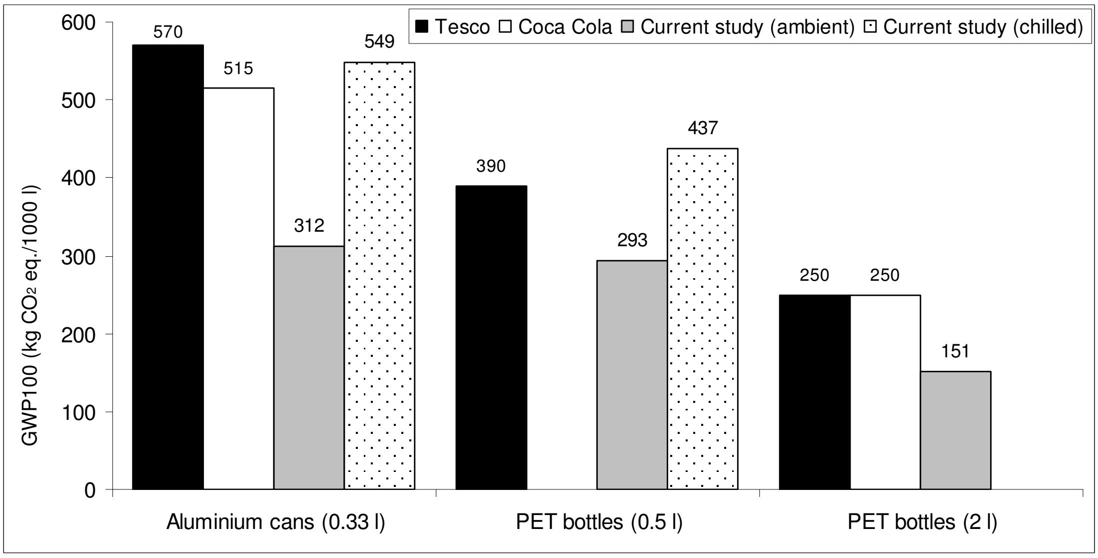

Figure 4-9 Comparison of global warming potential with other studies

4.1.3.7 Other environmental impacts

As shown in Figure 4-10, the drink packaged in the 2 l PET bottle has the lowest impacts for seven out of eleven impacts: primary energy demand (PED), abiotic depletion (ADP), acidification (AP), human toxicity (HTP), freshwater and marine aquatic toxicity (FAETP and MAETP) and photochemical oxidant creation (POCP) potentials. The aluminium can is the best option for three of the impacts considered here: eutrophication (EP), terrestrial ecotoxicity (TETP) and ozone depletion (ODP).

The glass bottle, on the other hand, is the worst option for six impact categories: PED, ADP, AP, HTP, TETP and POCP. The aluminium cans have the highest HTP and MAETP while the 0.5 l PET bottles have the highest EP and FAETP. The HTP from aluminium cans is particularly high (14 times higher than the next worst option, glass) - this is due to the emissions of polyaromatic hydrocarbons (PAH) from the cans production which contributes to 97% of this impact. The life cycle stage contributions to these impacts are shown in Figure 4-11 to Figure 4-14. Similar to GWP, the packaging stage is the major ‘hot spot’ for all the impacts except for water demand (WD) and EP where the ingredients and waste management are also significant. WD is mainly due to consumption of water for cultivation of sugar cane while EP is due to the chemical oxygen demand (COD) and nitrogen emissions to water from sugar production.

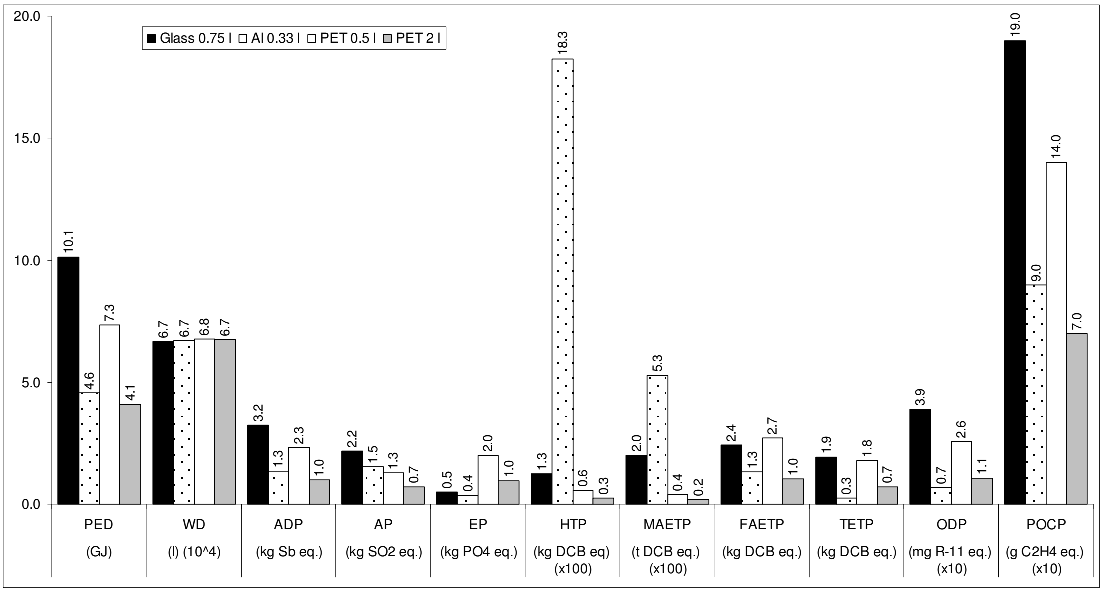

Figure 4-10 Environmental impacts (other than GWP) in the life cycle of the carbonated drink

[Some values have been scaled to fit on the graph. To obtain the original values for the scaled impact, its value should be multiplied by the factor shown in brackets. *PED* primary energy demand, *WD* water demand, *ADP* abiotic depletion potential, AP acidification potential, *EP* eutrophication potential, http human toxicity potential, *MAETP* marine aquatic ecotoxicity potential, *FAETP* freshwater aquatic ecotoxicity potential, *TETP* terrestrial ecotoxicity potential, *ODP* ozone depletion potential, *POCP* photochemical ozone creation potential.]

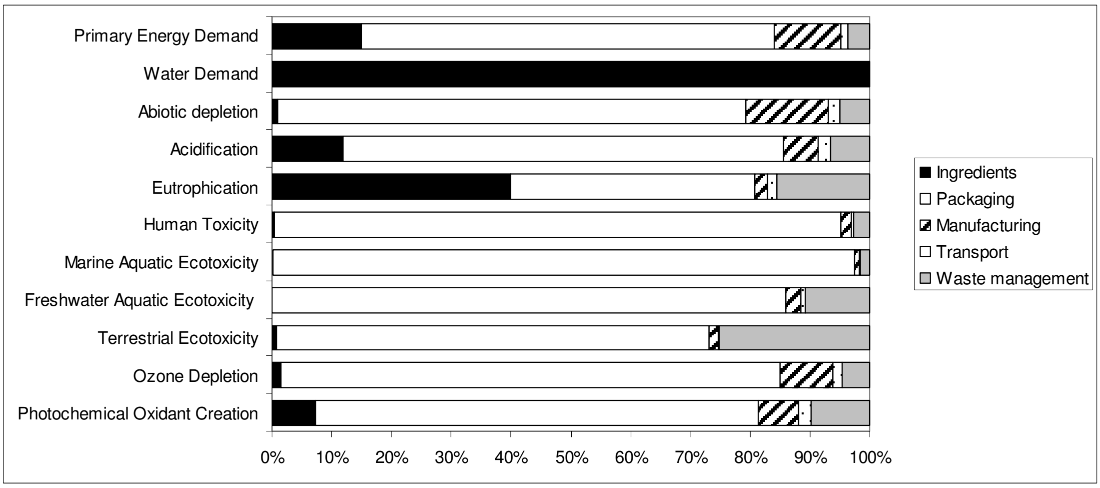

Figure 4-11 Contribution of different life cycle stages to the environmental impacts for the glass bottle

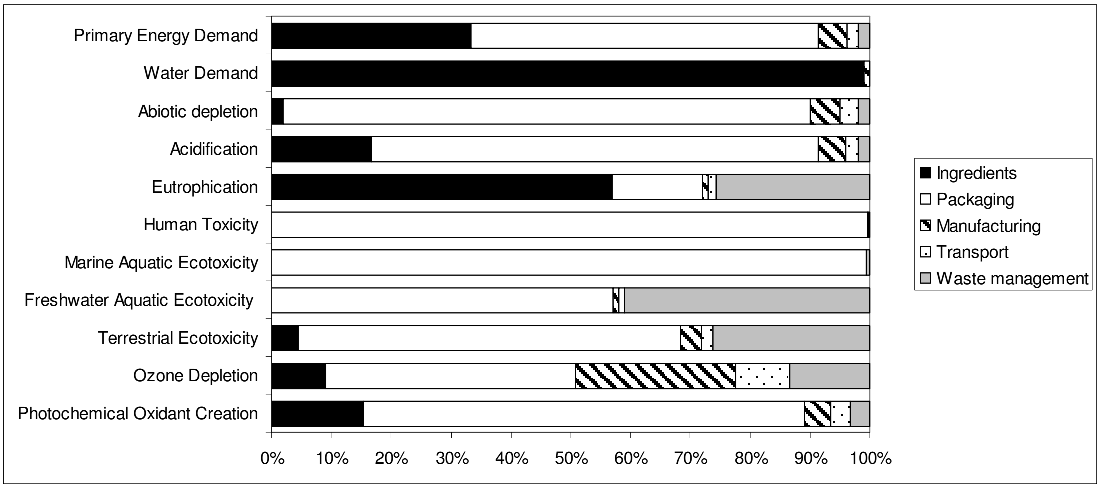

Figure 4-12 Contribution of different life cycle stages to the environmental impacts for the aluminium can

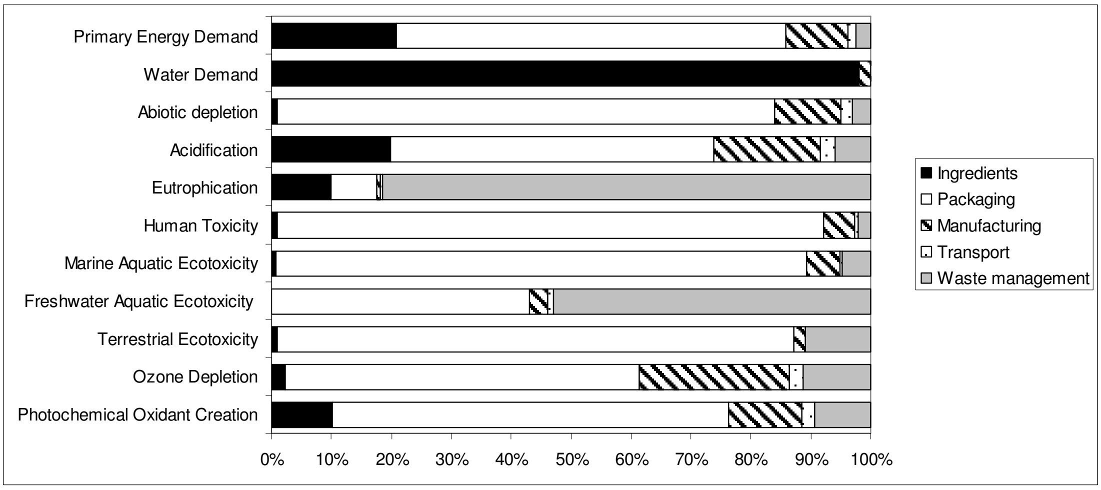

Figure 4-13 Contribution of different life cycle stages to the environmental impacts for the 0.5 l PET bottle

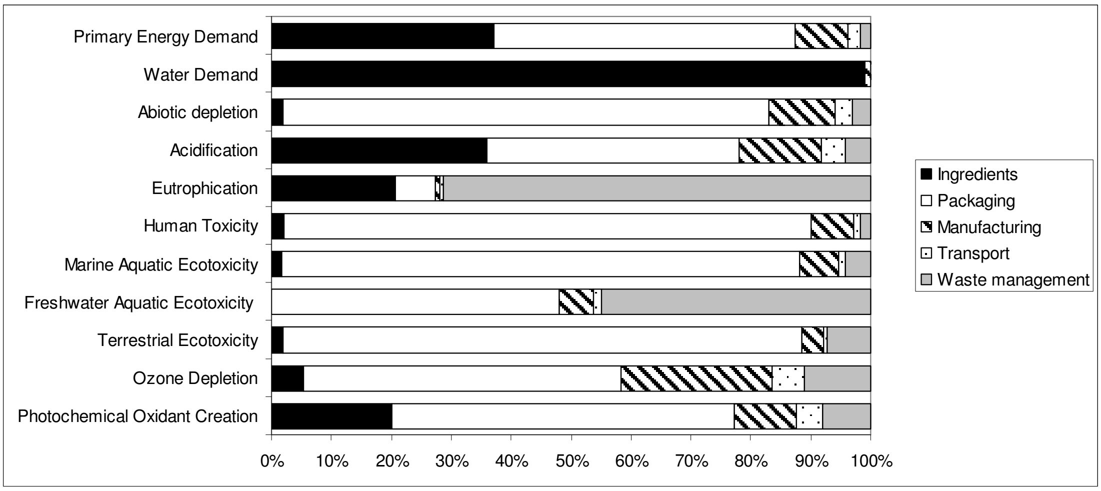

Figure 4-14 Contribution of different life cycle stages to the environmental impacts for the 2 l PET bottle

The performance of cane and beet sugar has also been compared with regard to other environmental impact categories. As can be seen in Figure 4-15, cane sugar produced in Brazil performs better than beet sugar produced in Switzerland in 5 out of 10 environmental impact categories (AP, EP, MAETP, ODP and ADP). On the other hand, beet sugar shows lower impacts with regards to FAETP, HTP, POCP, TETP and water consumption. Similar to the results in Figure 4-15, Renouf et al. (2008) found sugarcane to be more advantageous than sugar beet in relation to fossil energy input due to the availability of bagasse as an energy source, as well as acidification due to field emissions of nitrogen oxides (from soil denitrification) and ammonia (from urea volatilisation). Sugar beet, on the other hand, demonstrated advantages over sugarcane in relation to eutrophication and water use. EP was found to be mainly due to nitrogen oxide emissions (from soil denitrification), phosphorus (from runoff), leaching of nitrates and ammonia (from volatilisation of applied urea) (Renouf et al., 2008). However, it is important to note that the results are sensitive to factors including the nature and quantities of co-products which may provide environmental credits, crop yields, as well as other region-specific factors (Renouf et al., 2008). Therefore, these trade-offs, as well as other economic and social factors, have to be considered and investigated in more detail before recommendations can be made with regard to sourcing sugar from alternative sources for soft drinks production.

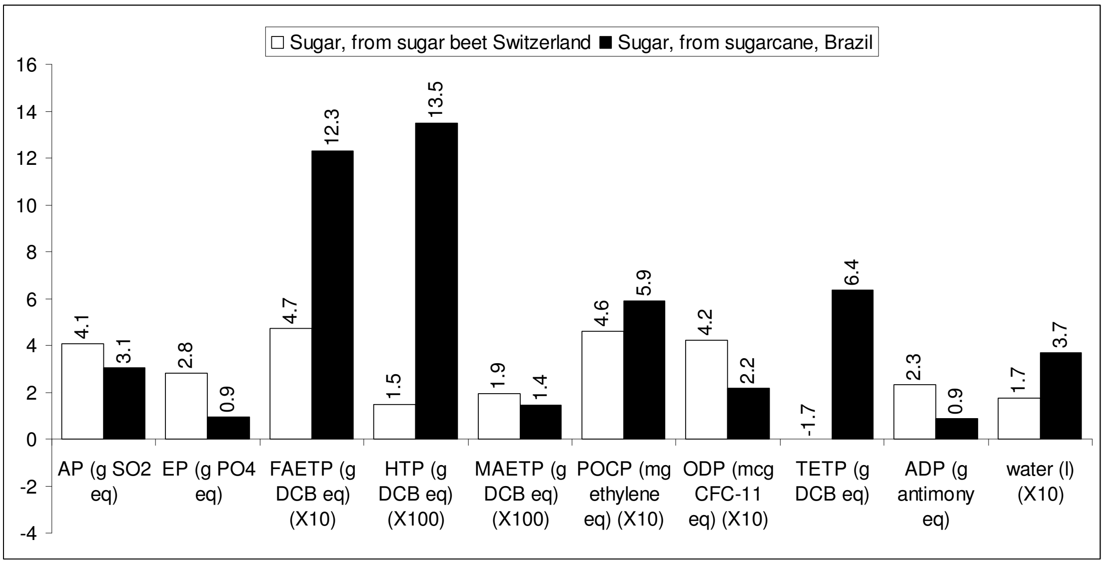

Figure 4-15 Environmental impacts of cane and beet sugar
[Some values have been scaled to fit on the graph. To obtain the original values for the scaled impact, its value should be multiplied by the factor shown in brackets.]

4.1.3.8 Environmental impacts of the UK carbonated soft drinks sector

As mentioned in section 4.1.2.1, the formulation of carbonated soft drink considered here is similar for over 95% of the ingredients to other carbonated soft drinks (BSDA, 2011; Key Note, 2011). Therefore, to estimate the potential environmental impacts of the carbonated drinks sector in the UK, the findings of this study have been extrapolated for the total production of all carbonated drinks of 6,400 million litres in 2010, representing 45% of total soft drinks production. Of this amount, 57%, 26% and 3% were packaged in PET, cans and glass, respectively, while the remaining 14% were consumed from dispensers and other (unspecified) packaging formats. Considering only the drinks packaged in PET, cans and glass bottles (86% of the total production), the estimated environmental impacts are as given in Figure 4-16 and Figure 4-17. For example, production of carbonated drinks in the UK was responsible for over 1.4 million tonnes of CO_2 eq. emissions in 2010 (Figure 4-16). This represents 12% of the GHG emissions from the whole food and drink sector[15] or 0.24% of the UK total emissions in 2010[16]. Although the estimates for the GHG emissions are not directly comparable as in one case they represent the life cycle emissions (for the drinks) and mainly direct emissions (food and drink sector and UK

[15] Estimated based on the stated contribution by FDF (2008) and Defra (2006) of the food and drink sector of 2% to total UK GHG emissions.
[16] UK GHG emissions in 2010 are estimated at 582.4 million tonnes CO_2 eq. (DECC, 2011).

emissions), they are nevertheless an indication of the significance of the sector's contribution to the total GHG emissions. It can also be seen from Figure 4-16 that drinks packaged in aluminium cans contribute over 35% of the total GWP, although only 26% of the drinks are packaged in cans. Similarly, drinks in glass bottles contribute proportionally more than their market share – 10% compared to 3%, respectively.

While it is difficult to put the other environmental impacts in context, it can be noticed in Figure 4-18 that human and marine aquatic ecotoxicity are disproportionately higher for the aluminium cans than PET bottles, compared to their market share. As mentioned before, this is due to the high emissions of PAH and hydrogen fluoride, respectively. PET bottles, on the other hand, contribute much higher eutrophication, terrestrial ecotoxicity and ozone layer depletion potentials than their market share would suggest.

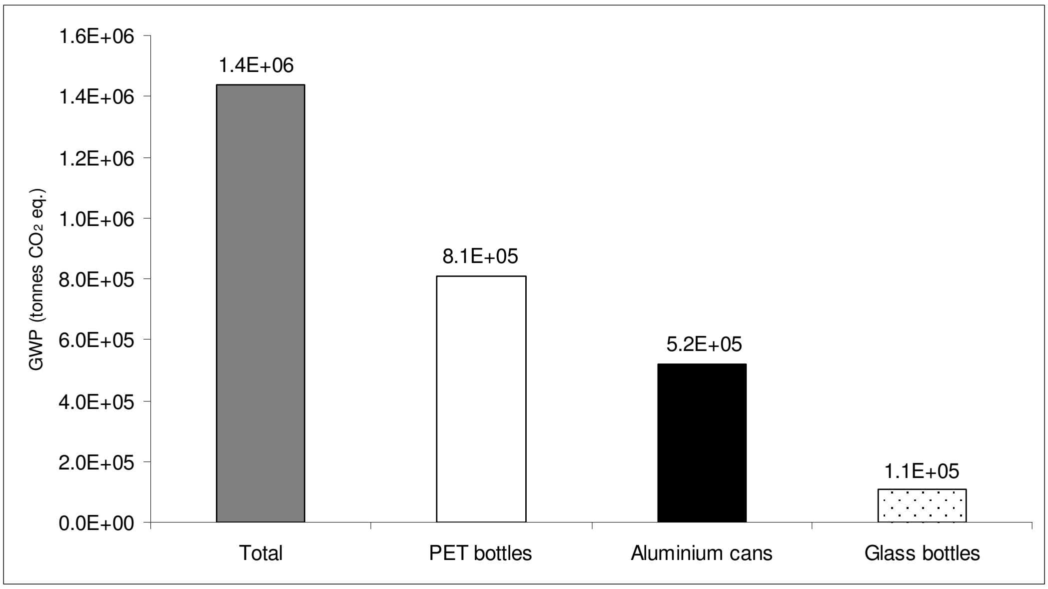

Figure 4-16 Annual global warming potential from the consumption of carbonated soft drinks in the UK
[Assumes that drinks are not refrigerated]

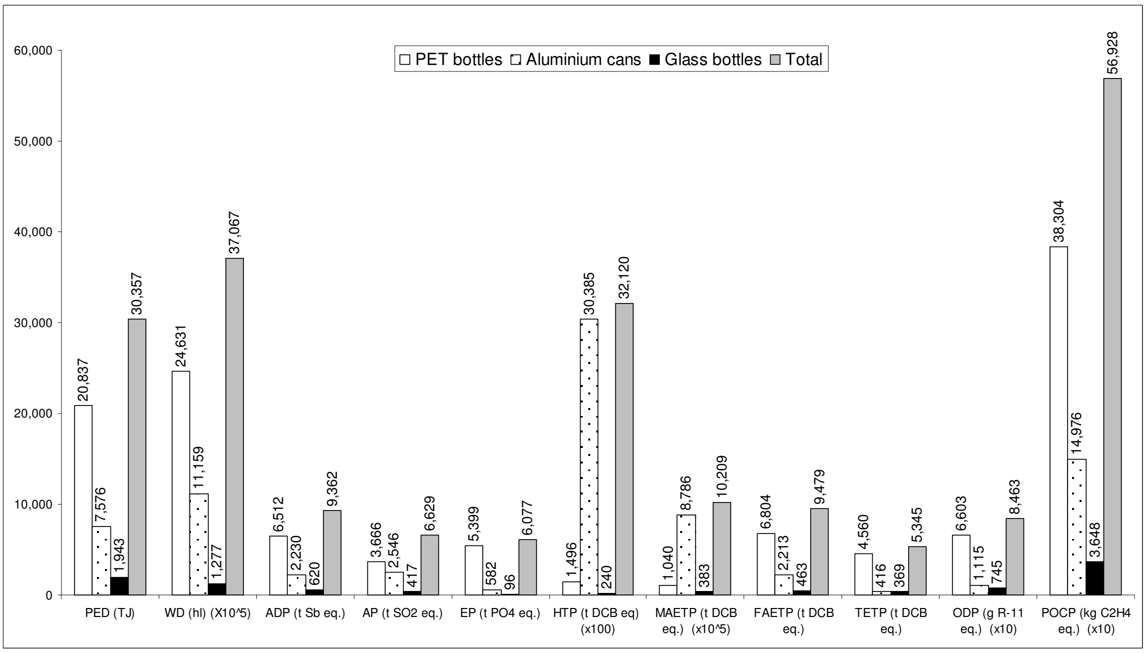

Figure 4-17 Life cycle environmental impacts of carbonated drinks in the UK
[Some values have been scaled to fit on the graph. To obtain the original values for the scaled impact, its value should be multiplied by the factor shown in brackets.]

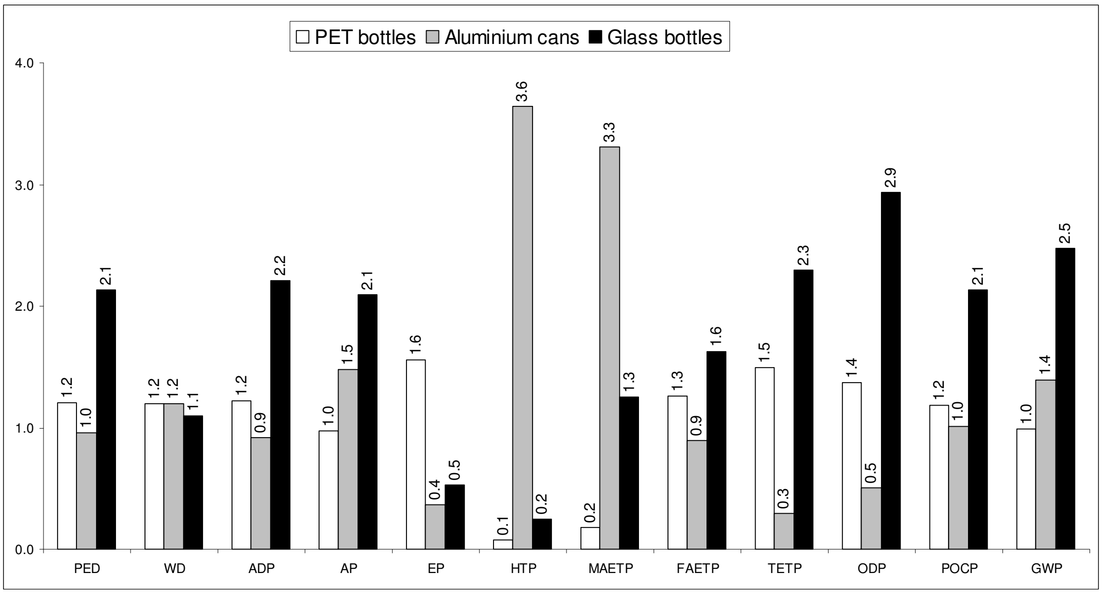

Figure 4-18 Comparison of environmental impacts for different types of packaging relative to their market share
[The values represent the ratio of the impact for each packaging type and its market share of 57% for PET, 26% for aluminium cans and 3% for glass bottles.]

4.2 Life cycle economic assessment

As mentioned previously, two economic aspects are considered: life cycle costs and value added. The methodology follows that used for LCA as far as possible; further details on the LCC and VA methodologies can be found in Chapter 3. The life cycle costs are considered from the perspective of the beverage manufacturer, consumer and the government.

4.2.1 Goal and scope

This LCC study has three main goals:

i. to estimate the life cycle costs and value added and identify the 'hot spots' in the life cycle of a carbonated soft drink produced and consumed in the UK;
ii. to analyse how these economic aspects may be affected by the type and size of different packaging used in the UK: glass bottle (0.75 l), aluminium can (0.33 l), PET bottle (0.5 l and 2 l);
iii. to estimate the life cycle costs and value added for the carbonated soft drinks sub-sector based on the findings from the first two goals of the case study and a UK market analysis.

Similar to the LCA, the functional unit is based on 1,000 litres of a carbonated soft drink while the sub-sectoral analysis considers total annual production and consumption of soft drinks in the UK.

4.2.2 Inventory data and assumptions

The life cycle inventory data are based on the LCA data presented in section 4.1.2. Primary production cost data have been obtained from literature, including the costs of ingredients in the beverage formulation, the costs of primary and secondary packaging materials, electricity and auxiliary materials for manufacturing, as well as waste management of in-process and post-consumer waste. It has been assumed that freight costs are included in the raw material costs; therefore the cost impact for each material in the life cycle includes transport. It is also assumed that the beverage manufacturer bears the costs of the ingredients, packaging materials and waste management of in-process waste. The consumer, on the other hand, bears the cost of disposal of post-consumer waste packaging (through taxes paid for waste disposal services). Revenues from recycling of in-process packaging waste are accrued to the beverage manufacturer, while revenues from recycling of post-consumer packaging waste are accrued to the government. More detail on the cost data are provided below.

4.2.2.1 Raw materials (ingredients)

The sources for the costs of ingredients in the life cycle of the carbonated drink are shown in Table 4-11. The cost data for delivery of water has been sourced from the public utility while the cost for sugar has been sourced from the international commodity market and may not accurately reflect prices in the UK.

Table 4-11 Raw material costs in the life cycle of the carbonated drink

Ingredient	Cost (£/1000 l)	Source of cost data
Water	2.1	United Utilities (2010)
Sugar	44.8	Indexmundi.com (2010)
Citric acid	1.8	ICIS (2010)
Carbon dioxide	0.5	Manufacturer
Sodium benzoate	0.8	ICIS (2010)
Caffeine	0.6	ICIS (2010)

4.2.2.2 Packaging

The costs of primary and secondary packaging materials are summarised in Table 4-12 and Table 4-13, respectively. It is important to note that the costs shown do not include fabrication of the final packaging (bottles, cans, closures, labels, crates, etc). This is a limitation of the study but due to the lack of data (confidentiality), it was not possible to obtain these data.

Table 4-12 Primary packaging costs in the life cycle of the carbonated drink

Packaging type	Cost (£/1000 l)	Source of cost data
Glass bottle (0.75 l)		
Glass (65% primary content)[a]	264.2	Aliexpress.com (2010)
Recycled glass cullet (35% recycled content)[b]	5.9	WRAP (2008)
Aluminium alloy (closure)	2.4	LME (2011)
Kraft paper label	0.5	FOEX indexes (2011)
Aluminium can (0.33 l)		
Primary aluminium (52% primary content)[c]	22.9	LME (2011)
Recycled aluminium (48% recycled content)[d]	14.8	Letsrecycle.com (2010)
Primary aluminium (can ends)[c]	11.9	LME (2011)

PET bottle (0.5 l)		
Primary PET (bottle)[e]	62.3	WRAP (2011)
Primary HDPE (closure)[f]	7.1	Plasticsinfomart.com (2011)
Primary PP (label)[g]	0.6	WRAP (2011)
PET bottle (2 l)		
Primary PET (bottle)[e]	27.9	WRAP (2011)
Primary HDPE (closure)[f]	1.8	Plasticsinfomart.com (2011)
Primary PP (label)[g]	0.5	WRAP (2011)

[a] Price of white container glass per kg; recycled content not indicated.
[b] In the absence of more reliable data, the average price of recycled green glass cullet in the UK has been assumed.
[c] Represents the seller price of high grade primary aluminium on the commodity market.
[d] The price shown represents the market price per kg for baled used aluminium cans in the UK market.
[e, f, g] The prices shown represent the market prices for primary PET, HDPE and PP granulate in the UK market.

Table 4-13 Secondary packaging costs in the life cycle of the carbonated drink

Packaging type	Cost (£/1000 l)	Source of cost data
Glass bottle (0.75 l)		
Corrugated board (top tray)	0.1	WRAP (2011)
Kraft paper (secondary label)	8.8×10^{-4}	FOEX indexes (2011)
LDPE (bag and stretch wrap)	1.4	WRAP (2011)
Wood (pallet)	8.0×10^{-5}	Indexmundi.com (2011)
Filled bottles to retail		
LDPE (stretch wrap)	0.4	WRAP (2011)
HDPE (crate)	2.6	WRAP (2011)
Wood (pallet)	0.4	Indexmundi.com (2011)
Aluminium can (0.33 l)		
PET (banding)	1.1	WRAP (2011)
LDPE (stretch wrap)	4.6×10^{-3}	WRAP (2011)
Kraft paper (secondary label)	0.1	FOEX indexes (2011)
Filled cans to retail		
LDPE (stretch wrap)	2.4	WRAP (2011)
Cardboard (layer pads)	0.7	WRAP (2011)
Kraft paper (secondary label)	3.1×10^{-2}	FOEX indexes (2011)
Wood (pallet)	0.2	Indexmundi.com (2011)
PET bottle (0.5 l)		
HDPE (box)	7.1	WRAP (2011)
Corrugated board	0.1	WRAP (2011)
LDPE (bags)	3.5×10^{-2}	WRAP (2011)
Wood (pallets)	0.5	Indexmundi.com (2011)
Filled bottles to retail		
LDPE (stretch wrap)	3.9	WRAP (2011)
Cardboard (layer pads)	0.4	WRAP (2011)
Kraft paper (secondary label)	0.1	FOEX indexes (2011)
Wood (pallet)	0.2	Indexmundi.com (2011)

PET bottle (2 l)		
HDPE (box)	4.2	WRAP (2011)
Corrugated board	1.4×10^{-2}	WRAP (2011)
LDPE (bags)	1.2×10^{-2}	WRAP (2011)
Wood (pallets)	3.4×10^{-2}	Indexmundi.com (2011)
Filled bottles to retail		
LDPE (stretch wrap)	2.5	WRAP (2011)
Cardboard (layer pads)	0.1	WRAP (2011)
Kraft paper (secondary label)	2.2×10^{-2}	FOEX indexes (2011)
Wood (pallet)	0.2	Indexmundi.com (2011)

4.2.2.3 Manufacturing

The costs of inputs for manufacturing and filling, as well as waste management of in-process waste are summarised in Table 4-14. Waste management of in-process waste packaging and effluents have been included in the manufacturing stage as these costs are accrued by the manufacturer. The system has been credited with the revenue for recycling of in-process waste (shown in Table 4-14).

Table 4-14 Manufacturing costs in the life cycle of the carbonated drink

Electricity/Material	Cost (£/1000 l)	Source of cost data
Electricity (drink manufacture)	1.6×10^{-2}	Electricityprices.org.uk (2011)
Glass bottle (0.75 l)		
Electricity (filling)	3.6	Electricityprices.co.uk (2011)
Effluents (wastewater treatment)	1.3	Scottish Water (2011)
In-process waste		
Corrugated board (landfill)	2.7×10^{-2}	WRAP (2011)
Corrugated board (recycling)	-0.1	WRAP (2012)
LDPE (landfill)	0.1	WRAP (2011)
LDPE (recycling)	-1.0E-3	WRAP (2012)
Wood (landfill)	1.1E-5	WRAP (2011)
Aluminium can (0.33 l)		
Electricity (filling)	3.5	Electricityprices.org.uk (2011)
Effluents (wastewater treatment)	1.2	Scottish Water (2011)
In-process waste		
PET (landfill)	0.1	WRAP (2011)
PET (recycling)	-8.0×10^{-4}	WRAP (2012)
LDPE (landfill)	2.3×10^{-4}	WRAP (2011)
LDPE (recycling)	-3.8×10^{-6}	WRAP (2012)
Kraft paper (landfill)	1.8×10^{-3}	WRAP (2011)
Kraft paper (recycling)	-5.8×10^{-3}	WRAP (2012)
PET bottle (0.5 l)		
Electricity (filling)	4.2	Electricityprices.org.uk (2011)
Effluents (wastewater treatment)	1.7	Scottish Water (2011)
In-process waste		
HDPE (landfill)	0.4	WRAP (2011)
HDPE (recycling)	-6.0×10^{-3}	WRAP (2012)
LDPE (landfill)	1.7×10^{-3}	WRAP (2011)

LDPE (recycling)	-2.9×10^{-5}	WRAP (2012)
Corrugated board (landfill)	9.1×10^{-3}	WRAP (2011)
Corrugated board (recycling)	-3.8×10^{-2}	WRAP (2012)
Wood (landfill)	6.8×10^{-2}	WRAP (2011)
PET bottle (2 l)		
Electricity (filling)	1.7	Electricityprices.org.uk (2011)
Effluents (wastewater treatment)	1.3	Scottish Water (2011)
In-process waste		
HDPE (landfill)	0.2	WRAP (2011)
HDPE (recycling)	-3.4×10^{-3}	WRAP (2012)
LDPE (landfill)	5.8×10^{-4}	WRAP (2011)
LDPE (recycling)	-9.6×10^{-6}	WRAP (2012)
Corrugated board (landfill)	2.6×10^{-3}	WRAP (2011)
Corrugated board (recycling)	-1.1×10^{-2}	WRAP (2012)
Wood (landfill)	4.6×10^{-3}	WRAP (2011)

The costs of in-process waste recycling have been assumed as revenues for the beverage manufacturer.

4.2.2.4 Waste management (post-consumer)

The waste disposal costs for the post-consumer packaging waste are summarised in Table 4-15. The non-recycled content of the glass bottles and aluminium cans are sent to landfill at the end of life. As previously mentioned, 24% and 76% of all plastic wastes are recycled and sent to landfill, respectively. The system has been credited for recycling of plastics at the end of life.

Table 4-15 Waste management costs in the life cycle of the carbonated drink

Material	Cost (£/1000 l)	Source of cost data
Glass bottle (0.75 l)		
Glass (65% content)	39.4	WRAP (2011)
Aluminium alloy (closure)	0.1	WRAP (2011)
Kraft paper (label)	0.1	WRAP (2011)
Aluminium can (0.33 l)		
Aluminium (52% content can body)	1.2	WRAP (2011)
Aluminium (can end)	0.6	WRAP (2011)
PET bottle (0.5 l)		
PET (landfill)	2.8	WRAP (2011)
PET (recycling)	-4.6×10^{-2}	WRAP (2012)
HDPE (landfill)	0.4	WRAP (2011)
HDPE (recycling)	-5.9×10^{-3}	WRAP (2012)
PP (landfill)	4.0×10^{-2}	WRAP (2011)
PP (recycling)	-6.7×10^{-4}	WRAP (2012)
PET bottle (2 l)		
PET (landfill)	1.2	WRAP (2011)
PET (recycling)	-2.1×10^{-2}	WRAP (2012)
HDPE (landfill)	8.7×10^{-2}	WRAP (2011)
HDPE (recycling)	-1.4×10^{-3}	WRAP (2012)
PP (landfill)	3.5×10^{-2}	WRAP (2011)
PP (recycling)	-5.8×10^{-4}	WRAP (2012)

The costs of post-consumer waste recycling have been assumed as revenues for the government.

4.2.2.5 Consumer costs

As observed in section 4.2.2, it has been assumed that the consumer bears the costs of disposal of post-consumer packaging waste through taxes paid for waste disposal services. These are shown as landfill costs in Table 4-15. The retail price of the product which has been used to estimate VA can also be classified as consumer costs. The retail prices are shown in Table 4-16.

Table 4-16 Average retail price of the carbonated soft drink in the UK market

Type of packaging for product	Average UK retail price (£/1000 l)[a]
Glass bottle (0.75 l)	1,973
Aluminium can (0.33 l)	1,404
PET bottle (0.5 l)	2,000
PET bottle (2 l)	785

[a] Data based on the average retail price of the actual product (not named for confidentiality reasons) in the major UK retail outlets: Asda, Tesco and Sainsburys accessed 25 July 2011.

4.2.2.6 Data quality

Using the data quality assessment approach presented in Chapter 3 of this work, the LCC data quality has been assessed for the carbonated soft drink. The overall LCC data quality for the carbonated soft drink system has been estimated as 'Medium' for the different packaging systems considered in the study. More detail on the data quality assessment is provided in Appendix 3, section A3.1. A key limitation of the study is the assumption that market prices are equivalent to supply chain costs. Market prices have been used in the study due to the lack of data (confidentiality). However, the data quality analysis provides an indication of the level of confidence that can be placed in the results.

4.2.3 Life cycle economic impacts and interpretation

The results of the LCC are discussed first followed by the VA results. Following this, these two economic aspects are discussed for the whole carbonated soft drinks sub-sector.

4.2.3.1 Life cycle costing (LCC)

The results of the LCC are shown in Figure 4-19. The LCC results shown represent the life cycle costs accrued by the manufacturer, excluding the costs of post-consumer waste packaging disposal which are borne by the consumer through taxes paid for waste disposal services. However, post-consumer waste disposal costs account for 11%, 2%, 2% and 1% of the total LCC for the glass bottle, aluminium can, 0.5 l PET and 2 l PET bottle, respectively. The highest LCC (£373 per 1,000 l) is found for the glass bottle and the lowest (£91) for the 2 l PET bottle. The 0.5 l PET bottle and the aluminium can have the LCC of £141 and £111 per functional unit, respectively.

Figure 4-19, packaging is the major hot spot for the drink packaged in glass bottles, contributing 83% of the LCC. This is mainly (95%) due to the primary packaging. Packaging is also a key life cycle stage for the drink packaged in the aluminium can, 0.5 l PET and 2 l PET bottle, contributing 50%, 59% and 41%, respectively to the LCC, mainly due to primary packaging. Given that the costs of packaging only include the costs of raw materials and not their manufacture, the total costs would still be higher if these data were available and included in the total costs.

The LCC from the ingredients ranges from 13% (glass bottle) to 55% (2 l PET bottle) mainly (90%) due to sugar. Production of ingredients is also the major hot spot for the 2 l PET bottle. Despite accounting for 85% (wt) of the beverage formulation, water contributes only 4% of the LCC from ingredients. These costs are compared to the consumer costs in the next section which outlines the results for the VA.

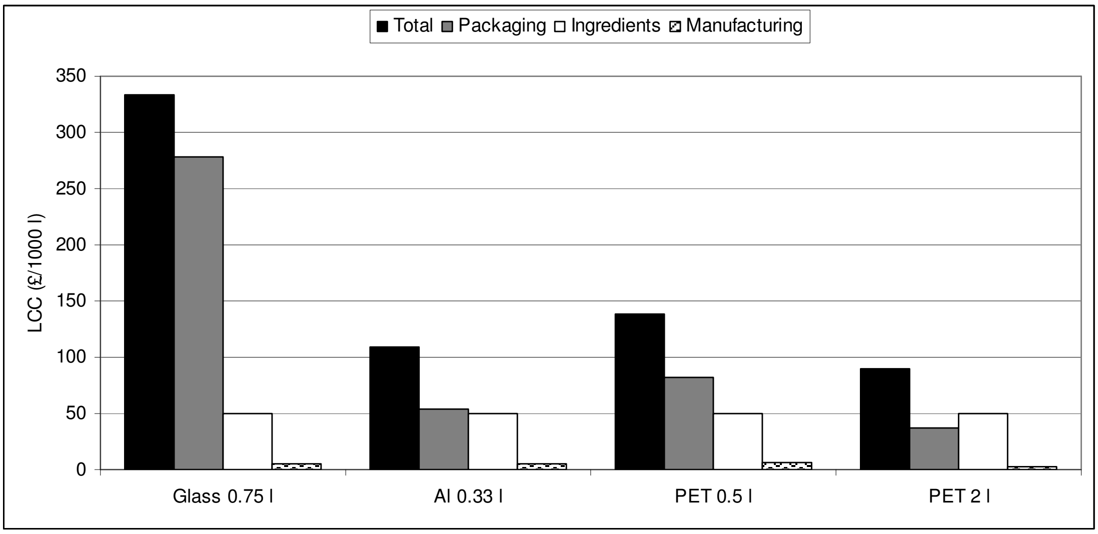

Figure 4-19 Life cycle costs of the carbonated drink for different types of packaging also showing the contribution of different life cycle stages
[The life cycle costs are shown from the manufacturer's perspective. Costs for disposal of post-consumer packaging waste, accounting for 11%, 2%, 2% and 1% of the LCC for the glass bottle, aluminium can, 0.5 l PET and 2 l PET bottle, respectively are not included as they are borne by the consumer through taxes paid for waste disposal services.]

4.2.3.2 Value added (VA)

The life cycle costs (from the manufacturer and consumer perspective), retail prices and results for VA accrued by the manufacturer are shown in Figure 4-20. The VA represents the difference between the retail prices and the LCC of the drink packaged in the different types of packaging. The retail price of the drink has been estimated based on the prices in the major retail outlets in the UK, as given in Table 4-16. As can be seen in Figure 4-20, the drink packaged in the 0.5 l PET bottle has the highest VA (£1,862 per 1,000 l) while the drink packaged in the 2 l PET bottle has the lowest VA (£695 per 1,000 l). The drink packaged in the aluminium can and the glass bottles have the VA of £1,295 and £819, respectively per functional unit. It is interesting to note that despite having the highest LCC, VA for the glass packaging is lower than that of the 0.5 l PET bottle and aluminium can. The higher VA values for the 0.5 l PET and aluminium cans may be contributing factors to the greater utilisation of plastics and cans for packaging of carbonated soft drinks (see section 4.1.3.8).

It is important to note that that VA accrued by the manufacturer has been estimated as the difference between the retail price (rather than the selling price to the retailer) and the life cycle costs for the manufacturer due to the lack of data (confidentiality). This is also a limitation of the study.

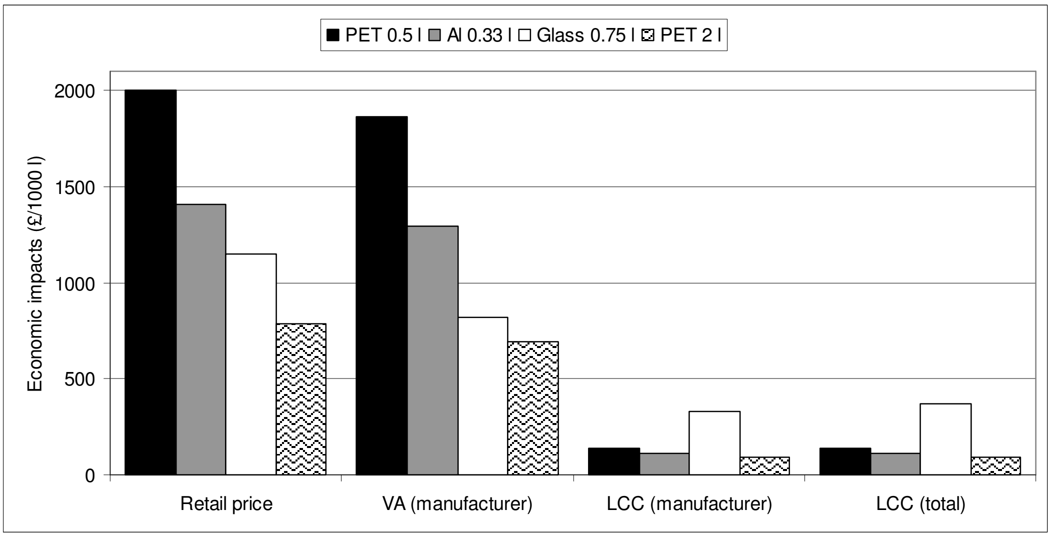

Figure 4-20 Value added of the carbonated drink for different types of packaging

4.2.3.3 Life cycle costs and value added at the sectoral level

Similar to the LCA, the LCC and VA from the carbonated soft drinks sub-sector have been estimated by extrapolating the LCC and VA results for the total production and consumption of 6,400 million litres in 2010. Considering the total consumption and the consumer penetration by market share for the different types of packaging (66% in plastics, 30% in cans and 3% in glass), the LCC and VA for the carbonated soft drinks sector are as shown in Figure 4-21. From Figure 4-21, it can be seen that production and consumption of carbonated soft drinks in the UK was responsible for about £679.5 million in life cycle costs in 2010. The VA from the carbonated soft drinks sector for 2010 is estimated to be about £7 billion. This amounts to about 0.5% of the UK GDP[17], demonstrating the significance of the life cycle economic impacts of the carbonated soft drinks sector on the UK economy. Plastics (0.5 and 2 l PET) are the major contributors to the sectoral economic impacts, accounting for 62% and 67% of the annual LCC and VA from the carbonated soft drinks sub-sector, respectively. Cans are the second most important type of packaging for economic impacts in the carbonated soft drinks sub-sector, accounting for 27% and 31% of the LCC and VA,

[17] Based on the stated UK GDP of £1,392,634 million for 2009 (Key Note, 2011); sourced from Economic and Labour Market Review, November 2010, National Statistics website.

respectively. Glass packaging, on the other hand, accounts for 11% and 2% of the sectoral LCC and VA, respectively.

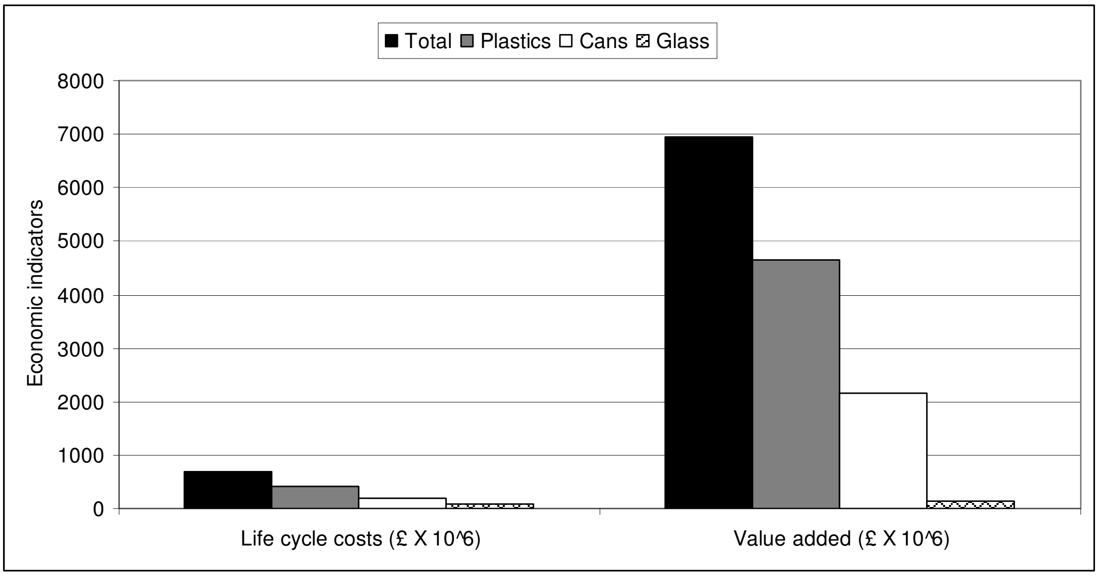

Figure 4-21 LCC and VA for the carbonated drinks sector in the UK

4.3 Comparison of environmental and economic sustainability

As shown in section 4.1.3.1, the glass bottle is the least preferred type of packaging regarding the GWP, with the total GWP estimated as 555 kg CO_2 eq./1,000 l. The 2 l PET bottle, on the other hand, is the preferred choice of packaging with a total GWP of 151 kg CO_2 eq./1,000 l. The drink in the aluminium can and 0.5 l PET has the GWP of 312 kg CO_2 eq. and 293 kg CO_2 eq./1,000 l, respectively. Similar to the GWP, the glass bottle is the worst option for six other environmental impacts categories (PED, ADP, AP, HTP and POCP) while the 2 l PET bottle has the lowest impacts for seven impact categories (PED, ADP, AP, HTP, FAETP and MAETP). The analysis in sections 4.2.3.1 and 4.2.3.2 also show that the glass bottle is the least preferred type of packaging from an economic perspective, accounting for the highest LCC and second lowest VA.

Figure 4-22 to Figure 4-25 show the contributions of different life cycle stages to the environmental impacts (from the LCA) and economic impact (illustrated by the LCC). As previously observed, this enables the identification and comparison of environmental and economic hot spots in the life cycle of the drink. It can be seen from Figure 4-22 to Figure 4-25 that packaging is the major 'hot spot' for most environmental and economic impacts. The raw materials stage is also an important contributor to WD, EP and LCC, while waste management is an important contributor to EP and FAETP.

Overall, the results of the life cycle environmental and economic analyses suggest that PET is a more sustainable choice of packaging than glass and aluminium. The results also suggest that the aluminium is more sustainable than glass, showing lower environmental impacts (except HTP and MAETP), as well as lower LCC and greater VA than the glass bottle.

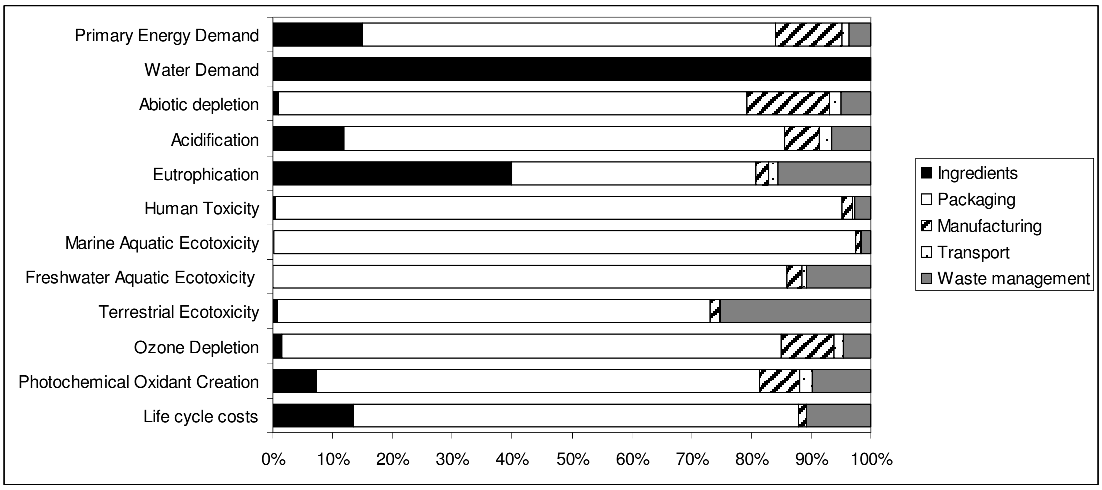

Figure 4-22 Contribution of different life cycle stages to the environmental and economic impacts for the glass bottle

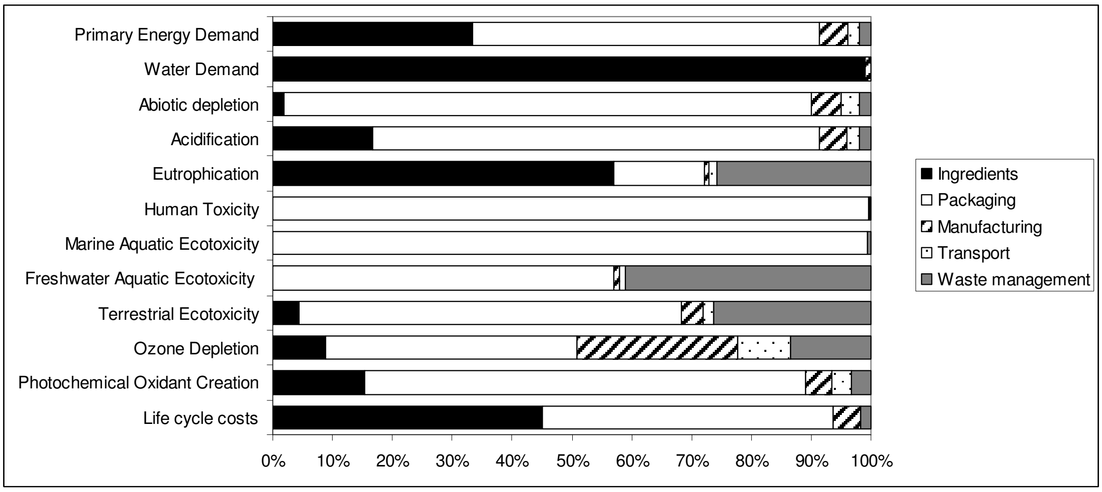

Figure 4-23 Contribution of different life cycle stages to the environmental and economic impacts for the aluminium can

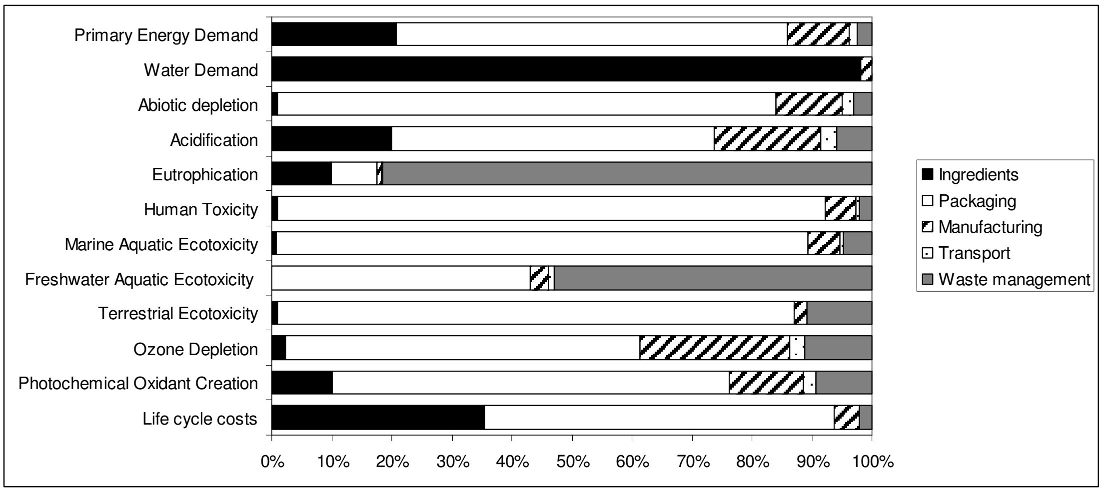

Figure 4-24 Contribution of different life cycle stages to the environmental and economic impacts for the 0.5 l PET bottle

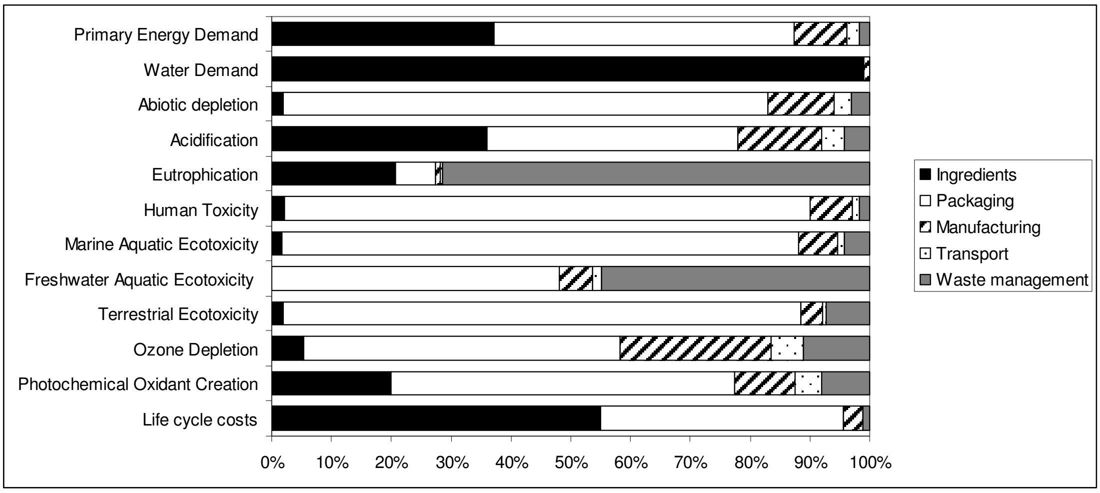

Figure 4-25 Contribution of different life cycle stages to the environmental and economic impacts for the 2 l PET bottle

4.4 Summary

The environmental and economic impacts in the life cycle of a carbonated soft drink have been quantified using the LCA, LCC and VA analysis. The objectives of the current case study have been met in that:

- the environmental and economic impacts in the life cycle of the carbonated drink have been estimated considering four packaging options: glass bottles (0.75 l), aluminium cans (0.33 l) and PET bottles (0.5 l and 2 l);
- the hot spots in the life cycle have been identified for the different types of packaging; and
- the life cycle environmental and economic impacts from the carbonated soft drinks sector have been estimated based on the findings of the LCA, LCC and the UK market analysis.

The results of the LCA indicate that the drink packaged in 2 l PET bottle has the lowest impact for most environmental impact categories including global warming potential. The glass bottle, on the other hand, is the least preferred option for most environmental impact categories. The results suggest that packaging is the major 'hot spot' for all the environmental impacts with the exception of water demand and eutrophication, where the ingredients and waste management stages are key contributors.

The sectoral analysis shows that production and consumption of carbonated soft drinks in the UK was responsible for over 1.4 million tonnes of CO_2 eq. emissions in 2010, representing 12% of the GHG emissions from the food and drink sector and 0.24% of the UK total emissions in 2010. The market analysis shows that drinks packaged in aluminium cans contribute over 35% of the total global warming potential, despite having a market share of only 26%. Similarly, drinks packaged in glass bottles contribute proportionally more than their market share – 10% compared to 3%, respectively.

The results of the economic assessment indicate that the drink packaged in the 2 l PET bottle has the lowest life cycle costs, while the drink packaged in the glass bottle has the highest life cycle costs. As for the environmental impacts, packaging is the major hot spot for the LCC of the drink packaged in the glass bottle, aluminium can and 0.5 l PET, contributing 83%, 50% and 59%, respectively. LCC for the drink in the 2 l PET bottle is dominated by the ingredients, accounting for 56% of the total. Despite accounting for only 11% of the drink formulation, sugar is responsible for

90% of the LCC from ingredients. Water, on the other hand, accounts for only 4% of the LCC from ingredients, despite accounting for 85% of the drink formulation.

Based on the results of the LCC and an estimate of the retail price of the drink, value added has been estimated as £1862, £1295, £819 and £695 per 1000 litres for the drink packaged in 0.5 l PET bottles, aluminium cans, glass bottles and 2 l PET bottles, respectively. The sectoral analysis suggests that the carbonated soft drinks sector was responsible for life cycle costs of about £679.5 million in 2010. Value added for the UK carbonated soft drinks sector has been estimated at about £7 billion in 2010 or about 0.5% of the UK GDP. The highest contribution to the VA is from plastics (67%) and the lowest from glass packaging (2%).

Overall, based on the results of this work, PET is the most sustainable option for the environmental and economic aspects considered here while glass is the least sustainable. A comparison of the different life cycle stage contributions to the environmental impacts shows that packaging and ingredients are the key 'hot spots' in the life cycle of the carbonated soft drink. They should therefore, be the focus of performance improvement strategies.

A similar analysis has been carried out for the life cycle of beer produced and consumed in the UK. The findings of the environmental and economic analyses are presented in the next chapter.

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5 LIFE CYCLE ASSESSMENT OF ENVIRONMENTAL AND ECONOMIC SUSTAINABILITY OF BEER

This chapter presents the life cycle assessment of environmental and economic sustainability of beer (lager). Life cycle assessment (LCA) is used to quantify the environmental impacts while the economic aspects are quantified using life cycle costing (LCC) and value added (VA) analysis. A similar analysis is also carried out for the whole beer sector based on the results of the LCA, LCC, VA and UK market analyses. The LCA results are discussed first followed by the LCC and VA analyses.

5.1 Life Cycle Assessment

This LCA study follows the LCA methodology as specified in the ISO 14040/44 standards (ISO, 2006a&b), starting with definition of the goal and scope, followed by inventory, impact assessment and interpretation of results. Various sensitivity analyses are also performed as detailed below.

5.1.1 Goal and scope of the LCA

The current LCA case study has four main goals:

i. to estimate the environmental impacts and identify the hot spots in the life cycle of beer (lager) produced and consumed in the UK;
ii. to analyse how the environmental impacts may be affected by the type and size of different packaging used in the UK: glass bottles (0.33 l), aluminium cans (0.5 l) and steel cans (0.5 l);
iii. to estimate the life cycle impacts from the whole beer sub-sector based on the findings from the first two goals of the case study and a UK market analysis;
iv. to estimate the effect of potential improvement options on the life cycle environmental impacts.

For the first two goals of the study, the functional unit is based on 1,000 litres of beer. For the sectoral analysis, the functional unit considers total annual production and consumption of beer in the UK.

The life cycle of beer is shown in Figure 5-1. The system boundary of the study is from 'cradle to grave', comprising the following life cycle stages:

- ***Raw materials***: water supply, production and use of fuels, and other materials for cultivation and harvest of barley, and processing of barley malt;
- ***Packaging***: production of primary and secondary packaging such as glass bottles, steel bottle tops, kraft paper labels, paperboard crates, aluminium cans and steel cans;
- ***Manufacturing and filling***: production and use of electricity and steam for manufacture of beer and filling in bottles and cans;
- ***Transport***: transport of barley malt and primary packaging materials to the brewery, packaged product to retail and post-consumer waste to waste disposal; and
- ***Waste management***: wastewater treatment of effluents from the brewery and disposal of post-consumer waste packaging.

The following activities are excluded from the system boundary due to lack of data:

- packaging of the raw materials;
- refrigerated storage at the retail stage; and
- transport of consumers to purchase the product and any storage at consumer.

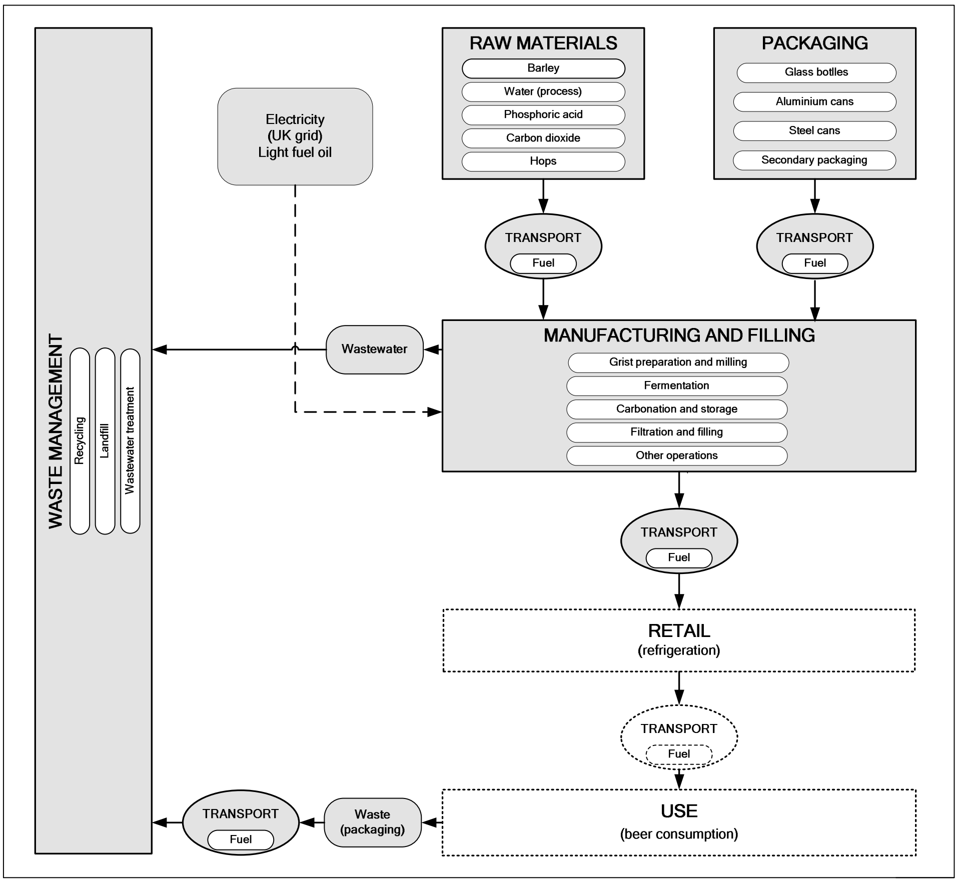

Figure 5-1 The life cycle of beer

5.1.2 Inventory data and assumptions

Primary production data have been obtained from a brewing company, including the amounts of raw materials for production of beer, the amounts of primary and secondary packaging materials, electrical energy consumed at the manufacturing stage as well as transport modes and distances. All other data have been sourced from the CCaLC (2011), Ecoinvent (2010) and Gabi (PE, 2010) databases. More detail on the inventory data and their sources is provided below.

5.1.2.1 Raw materials

The main ingredients for beer production are water, barley, hops and yeast (BBPA, 2007) as well as carbon dioxide (for carbonation). The ingredients and their respective quantities considered in the analysis are shown in Table 5-1. Auxiliary materials used during brewing such as light fuel oil, sodium hydroxide, sulphuric acid, phosphoric acid and diatomaceous earth have also been included in the analysis. It has been assumed that all raw materials are sourced from the UK. Liquefied carbon dioxide has been sourced from different production processes as 'waste'. However, fossil origin of carbon dioxide has also been considered within a sensitivity analysis.

Table 5-1 Raw materials for beer production[a]

Raw and auxiliary materials	Quantity/1000 l
Barley	73 kg
Water (process)	8,430 l
Hops	1.3 kg
Yeast	21 kg
Diatomaceous earth	1.7 kg
Sodium hydroxide	9.0 kg
Phosphoric acid	2.0 kg
Sulphuric acid	2.5 kg
Carbon dioxide	30 kg
Light fuel oil	36.6 l

[a]All LCI data from the Ecoinvent (2010) database

5.1.2.2 Packaging

The types of primary and secondary packaging materials are summarised in Table 5-2. Glass bottles, aluminium and steel cans are typically used as beer packaging in the UK. The glass bottles are assumed to contain 85% recycled content based on the UK situation for coloured container glass as coloured glass is used predominantly for beer packaging in the UK (British Glass, 2009). The glass bottle tops and labels are made from steel and kraft paper, respectively, while the multi-pack crates are made from paperboard. The aluminium and steel cans have been assumed to contain 42% and 62% recycled content, respectively, based on the UK situation for aluminium and steel drinks packaging (EAA, 2007; DEFRA, 2009). Data has not been available for the plastic strapping material which is used to bind the cans together for retail in multi-packs therefore; this has not been included in the study. However, in order to accurately compare the impacts of the different types of packaging on an equivalent basis, a sensitivity analysis has been carried out considering only the primary packaging materials. This is shown in subsequent section 5.1.3.5.

Table 5-2 Components and weights of the packaging materials

Packaging type	Weight (kg/1000 l)	Source of LCI data
Glass bottles (0.33 l)	**691**	
Bottle (85% recycled content)	636.4	CCaLC (2011)
Top (steel)	6.1	Gabi (PE, 2010)
Multi pack crate (cardboard)	48.5	Ecoinvent (2010)
Aluminium cans (0.5 l)	**36**	
Can body (42% recycled content)	29.9	CCaLC (2011)
Can end (42% recycled content)	6.1	CCaLC (2011)
Steel cans (0.5 l)	**76**	
Can body (61.7% recycled content)	69.9	CCaLC (2011)
Can end (48% recycled content)	6.1	CCaLC (2011)

5.1.2.3 Manufacturing

The main process stages in manufacturing of beer are summarised below (BBPA, 2007). Prior to the brewing process, malted barley is obtained by soaking and draining the barley grains to initiate germination of the seed. Germination activates enzymes which convert starch and proteins into sugars and amino acids (Palmer, 1999). The grain is then dried in a kiln and stored for use in brewing. The beer production process begins with malted barley being crushed into a coarse powder known as grist. The grist is then transferred to a large vessel known as a mash tun where it is mashed with hot water. The sugars in the malt dissolve in the water to produce liquor called sweet wort, which is then boiled with hops in large vessels, known as coppers. After filtration and cooling of the wort, it is then blended with yeast and put in a fermentation vessel where yeast metabolises sugars in the wort to produce alcohol and carbon dioxide. The time required for this process varies from a few days to about 10 days depending on the yeast strain, fermentation parameters and taste profile (Galitsky et al., 2003). Addition of carbon dioxide and filtration are then carried out before filling the beer in bottles and cans. The total electricity, steam and compressed air consumed at the manufacturing and filling stage for the different packaging is shown in Table 5-3.

Table 5-3 Electricity and other utilities used in the manufacturing stage

Packaging type	Quantity per 1000 l	Source of data for amount	Source of LCI data
Glass bottles (0.33 l)			
Electricity	437.4 MJ	Manufacturer	Ecoinvent (2010)

Aluminium cans (0.5 l) Electricity Steam (filling) Compressed air (filling)	 415.0 MJ 6.0 MJ 10.1 NM^3	 CCaLC (2011) CCaLC (2011) CCaLC (2011)	 Ecoinvent (2010) Gabi (PE, 2010) Ecoinvent (2010)
Steel cans (0.5 l) Electricity Steam (filling) Compressed air (filling)	 414.6 MJ 6.0 MJ 10.1 NM^3	 CCaLC (2011) CCaLC (2011) CCaLC (2011)	 Ecoinvent (2010) Gabi (PE, 2010) Ecoinvent (2010)

5.1.2.4 Retail (refrigeration)

As part of the sensitivity analysis, the impact on the global warming potential (GWP) of refrigerated storage at the retailer has been assessed for the three types of packaging considered in this study. As shown in Table 5-4 and Table 5-5, GWP from both electricity consumption and refrigerant leakage has been considered. The following assumptions have been made:

- the refrigerant is assumed to be R404 with GWP of 3,860 kg CO_2 eq./kg (IPPC/TEAP, 2005);
- refrigerant charge is estimated at 3.5 kg/kW (van Baxter, 2002; IPPC/TEAP, 2005; DEFRA, 2007; Tassou et al., 2008);
- annual refrigerant leakage rate is assumed to be 15% (Tassou et al., 2008; US EPA, 2011);
- total display area of the refrigeration unit is 4.489 m^2 (BSI, 2005);
- the drink is refrigerated for one day (24 hours) before it is sold.

Table 5-4 Global warming potential from electricity consumption at retail

Drink packaged in:	Display cabinet type[a]	Electricity consumption[b] (kWh/m2.day)	Electricity consumption (kWh/m2.h)	Quantity of drink[c] (litres/m2 TDA[d])	Electricity consumption per volume of drink[e] (Wh/l.h)	GWP (g CO2 eq./l.day)
Glass bottles (0.33 l)	RVC3	13.8	0.58	70.6	8.2	120
Aluminium cans (0.5 l)	RVC3	13.8	0.58	106.9	5.4	72
Steel cans (0.5 l)	RVC3	13.8	0.58	106.9	5.4	72

[a]RVC3 = remote condensing unit, vertical, chilled
[b]Data from Tassou et al. (2008)
[c]Estimated by dividing the total drink volume in the display cabinet (317 litres for glass bottles and 480 litres for the aluminium and steel cans; estimated by visual examination) by the cabinet TDA (4.489 m^2)
[d]TDA = total display area

[e]Estimated by dividing the cabinet electricity consumption by quantity of drink

Table 5-5 Global warming potential from refrigerant leakage

Drink packaged in:	Volume of drink chilled[a] (l/year)	Refrigerant losses per year[b] (g/l)	Refrigerant losses per l of drink[c] (g/l.day)	GWP[d] (g/l)
Glass bottles (0.33 l)	115,705	1,050	9.0×10^{-3}	35.0
Aluminium cans (0.5 l)	175,200	1,050	6.0×10^{-3}	23.1
Steel cans (0.5 l)	175,200	1,050	6.0×10^{-3}	23.1

[a]Assuming 317 litres for the glass bottles and 480 litres for the aluminium and steel cans in the cabinet, respectively; see note c for Table 4-5.
[b]Estimated by multiplying the annual refrigerant losses (15%) by the refrigerant charge (3.5 kg/kW) and the power of the refrigerated display unit (2 kW)
[c]Estimated by dividing the annual refrigerant losses by the total volume of drink cooled annually.
[d]Estimated by multiplying the refrigerant losses per litre of drink per day by the GWP emission factor for R404A of 3,860 kg CO_2 eq./kg R404A.

5.1.2.5 Transport

The transport modes and distances for the beer system, as specified by the manufacturer, are summarised in Table 5-6. Where no specific data have been available, a generic distance of 100 km has been assumed for delivery of packaged beer to retail. Primary production data has not been available for the other raw materials. However, as part of the sensitivity analysis, the impact of delivery of the other raw materials to the brewery has been estimated using 40 t trucks and an average distance of 100 km. The results of this assessment are discussed in section 5.1.3.11.

Table 5-6 Transport modes and distances for the beer system[a]

Material	Transport mode	Distance (km)
Barley malt	Truck (40 t)	200
Primary packaging	Truck (32 t)	320
Packaged product	Truck (32 t)	100

[a]All LCI data from the Gabi (PE, 2010) database

5.1.2.6 Waste management

As indicated in Table 5-7, the relevant waste streams have been considered, including effluents from the brewery and post-consumer waste packaging. The effluents from the brewery are sent to wastewater treatment, while the average UK waste management options have been assumed for the post-consumer packaging waste (Table 5-7).

Table 5-7 Waste management options

Waste	Amount (kg/1000 l)	Waste management	Source of data for waste management option	Source of LCI data
Glass bottles (0.33 l)				
Glass bottles	95.5	15% landfilled	British Glass (2009)	ELCD (2010), Gabi (PE, 2010)
Steel tops	6.1	Landfilled	Manufacturer	PE (2010)
Cardboard crates	48.5	Landfilled	Manufacturer	Gabi (PE, 2010)
Aluminium cans (0.5 l)				
Aluminium can body	17.3	58% landfilled	EAA (2008); Defra (2009)	Gabi (PE, 2010)
Aluminium can ends	3.5	58% landfilled	EAA (2008); Defra (2009)	Gabi (PE, 2010)
Steel cans (0.5 l)				
Steel can body	26.8	38% landfilled	Defra (2009)	Gabi (PE, 2010)
Steel can ends	3.2	52% landfilled	Defra (2009)	Gabi (PE, 2010)
Effluent from brewery	6,997	Wastewater treatment	Manufacturer	Gabi (PE, 2010)

5.1.2.7 Data quality

Using the data quality assessment approach presented in Chapter 3, the LCA data quality has been assessed for the beer supply chain. The overall data quality has been estimated as ‘High’ for the different packaging systems considered in this work. More detail on the data quality assessment is given in Appendix 3, section A3.2.

5.1.3 Impact assessment and interpretation

The Gabi 4.3 LCA software has been used to model the system. The CML 2001 (Guinee et al., 2001) impacts characterisation method has been used to estimate the environmental impacts. In addition to the CML impacts, the primary energy demand and water demand have also been assessed. The global warming potential is discussed first followed by the other environmental impacts.

5.1.3.1 Global warming potential (GWP)

The results for the GWP of beer are given in Figure 5-2. The highest GWP (819 kg CO_2 eq. per 1,000 l of beer) is found for the glass bottles and the lowest (487 kg CO_2 eq. per 1,000 l of beer) for the steel cans. Beer packaged in the aluminium cans has the GWP of 551 kg CO_2 eq. per functional unit. As can also be seen from Figure 5-2, packaging is the major hot spot contributing between 37% (for the steel can) and 50% (for the glass bottle) of the total GWP. This is mainly (89%) due to carbon dioxide emissions from the production of glass bottles, aluminium and steel cans. It is interesting to note that the GWP for the drink in the aluminium can is higher than that of the drink in the steel can despite the steel can requiring a higher amount of material per functional unit. This may be explained by the higher energy demand for manufacturing of aluminium cans (for the assumed recycled contents of both cans).

The contribution to GWP from the raw materials stage ranges from 26% (glass bottles) to 36% (steel cans) and is mainly (65%) due to nitrous oxide emissions from barley cultivation and processing of barley malt (Figure 5-3). The contribution to GWP from production of carbon dioxide (14%) may be attributed to the energy required for its liquefaction and purification. Due to the assumed biogenic origin of carbon dioxide, its release during the use stage has not been considered in the analysis. However, assuming that is sourced from fossil sources, its release during consumption would add around 25.2 kg CO_2 eq. per functional unit or 0.03% (glass bottle) to 5.2% (steel cans). Light fuel oil is also an important contributor to the GWP from the raw materials stage due to its significant energy consumption compared to the other raw materials. The manufacturing stage accounts for 11%, 13% and 15% of the GWP for the glass bottle, aluminium and steel cans, respectively, mainly due to carbon dioxide emissions from the life cycle of electricity. It can be observed that the GWP from manufacturing is different for the various types of packaging due to the different amounts of electricity, steam and compressed air required for filling (see Table 5-3).

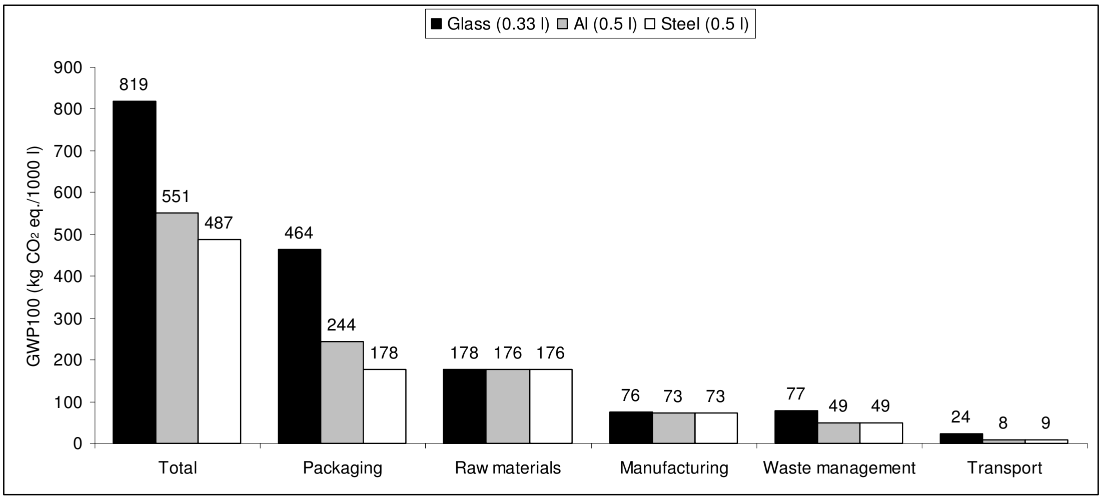

Figure 5-2 Global warming potential of beer for different types of packaging also showing the contribution of different life cycle stages

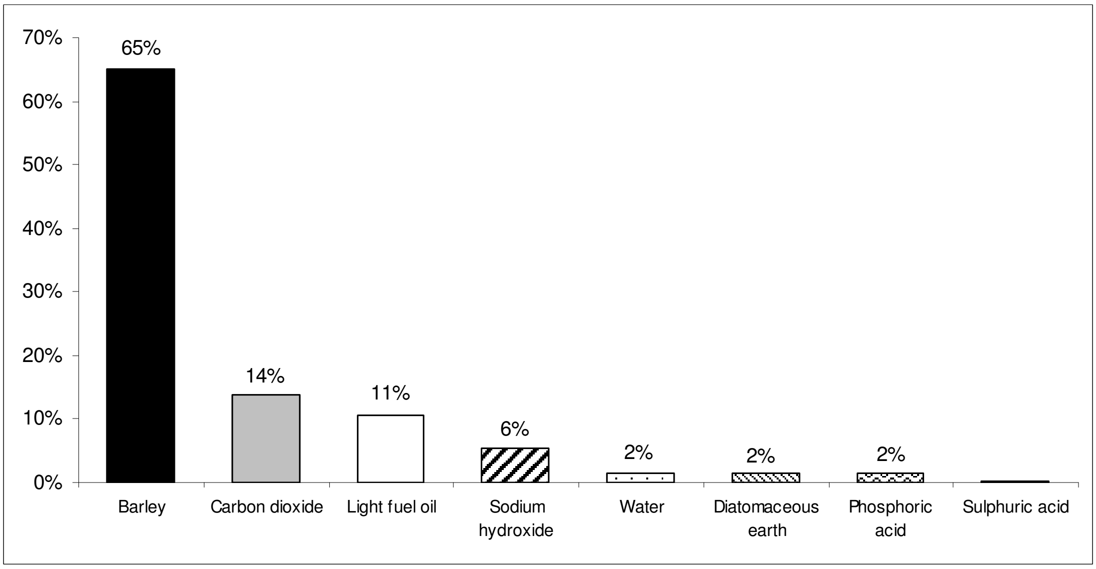

Figure 5-3 Contribution of raw materials and utilities to the global warming potential

5.1.3.2 Impact on GWP of refrigerated storage at retailer

The effect of refrigerated storage at retail on GWP has been assessed as part of the sensitivity analysis. The results shown in Figure 5-4 indicate that refrigerated storage adds 18%, 15% and 16% the GWP for the glass bottle, aluminium and steel can, respectively. Although the impact of refrigerated storage on the GWP is significant, most retailers would be reluctant to discontinue this practice due to consumer preference, which may impact negatively on sales.

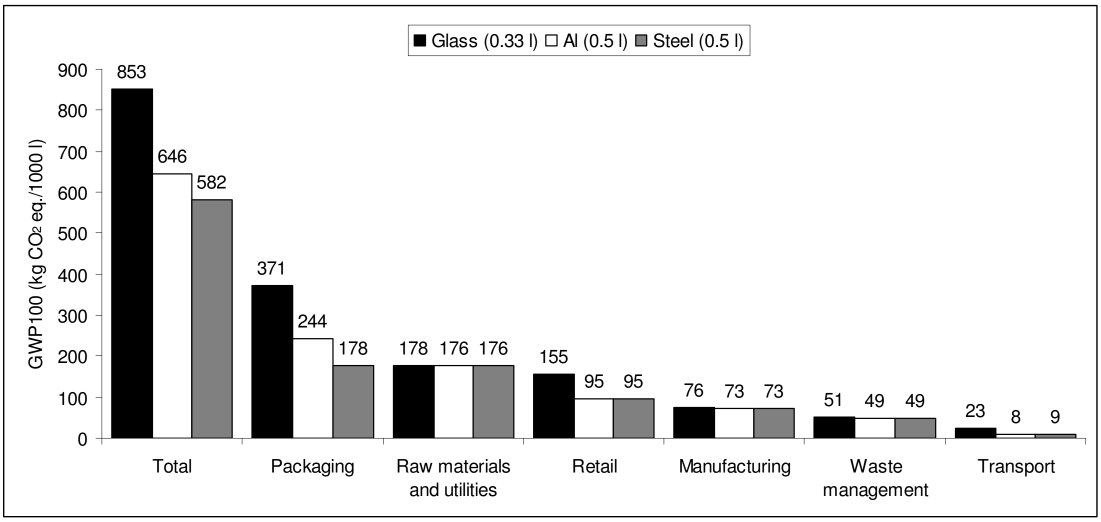

Figure 5-4 Contribution to global warming potential of retail (refrigerated storage) of the drink for the glass bottle (0.33 l), aluminium can (0.5 l) and steel can (0.5 l)

[The retail stage comprises electricity use and refrigerant leakage from refrigerated storage as calculated in Table 5-4 and Table 5-5]

5.1.3.3 Impact on GWP of conventional and organic barley

Having identified production of raw materials as a key life cycle stage for GWP and barley as an important contributor to GWP from this stage, the relative performance of barley production based on alternative agricultural systems (organic and conventional) has been investigated as part of the sensitivity analysis. Barley production is dominated by the EU-27, accounting for around 41% of global barley production (IndexMundi, 2012), while barley production in the UK stood at 5.5 million tonnes in 2011 (Defra, 2012). Although it has not been possible to determine the contribution of organic produce to total barley production in the UK, the total land area dedicated to organic arable production increased from 44,413 ha in 2003 to around 87,020 ha in 2006 (Scottish Government, 2006; Soil Association, 2006), suggesting a rise in the domestic demand for organic grain. The sensitivity analysis has considered the cradle-to-gate impacts of conventional and organic barley produced in Switzerland due to data availability. As can be seen in Figure 5-5, GWP from production of organic barley is 5% lower than that of conventional barley. In a study which compared the environmental burdens of organic and conventional agricultural commodities in the UK, Williams et al. (2006) found that GWP was only 2 to 7% less for organic than conventional field crops, showing strong agreement with the estimate in Figure 5-5. Another study found that the GWP of organic spring barley in Denmark was 38% lower than that of conventional barley (LCA Food Database, 2007), showing significant variation in the estimates between different studies. Applying the 5% GWP savings estimate to the whole beer system leads to only marginal GWP savings ranging from 1% (glass bottle) to 2% (steel can). The relative performance of conventional and organic barley in other environmental impact categories is given in Figure 5-20.

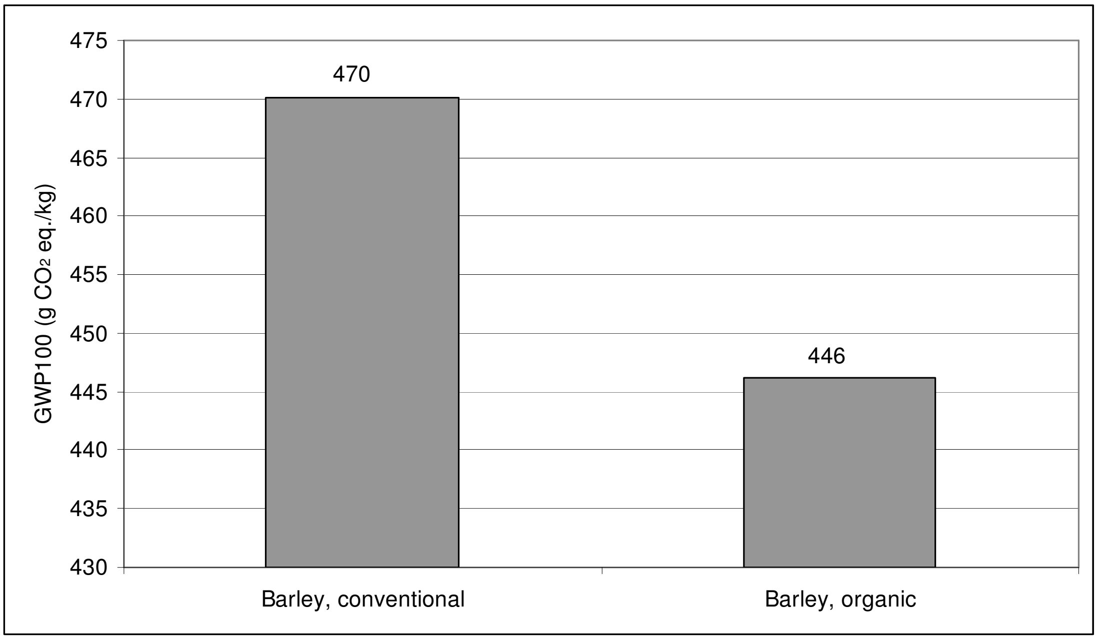

Figure 5-5 The effect of organic barley on global warming potential per kg of barley

[The life cycle impact assessment data represents conventional and organic barley produced in Switzerland. Data from the Ecoinvent (2010) database]

5.1.3.4 Other environmental impacts

As shown in Figure 5-6, beer packaged in the steel can has the lowest impacts for five out of 11 impact categories: primary energy demand (PED), abiotic depletion (ADP), acidification (AP), marine aquatic ecotoxicity (MAETP) and freshwater aquatic ecotoxicity (FAETP) potentials. The aluminium can is the best option for two of the impacts considered here: ozone depletion (ODP) and photochemical oxidant creation (POCP).

The glass bottle, on the other hand, is the worst option for nine impact categories: PED, WD, ADP, AP, EP, FAETP, TETP ODP and POCP. The aluminium cans have the highest HTP and MAETP. The HTP from the aluminium cans is particularly high (5 times higher than the next worst option, steel) – this is due to the emission of polyaromatic hydrocarbons (PAH) from the cans production which contributes 93% of this impact. MAETP from the aluminium cans is mainly due to hydrogen fluoride emissions from the cans production.

The contributions of the different life cycle stages to the environmental impacts are shown in Figure 5-7 to Figure 5-9. The packaging and raw materials stages are the major hot spots for all the impacts for the glass bottle and aluminium can. However, the manufacturing stage is a hot spot for POCP for the steel can, accounting for 57% of this impact. The contribution to POCP from the manufacturing stage is mainly due to nitrogen oxide and sulphur dioxide emissions from production of electricity.

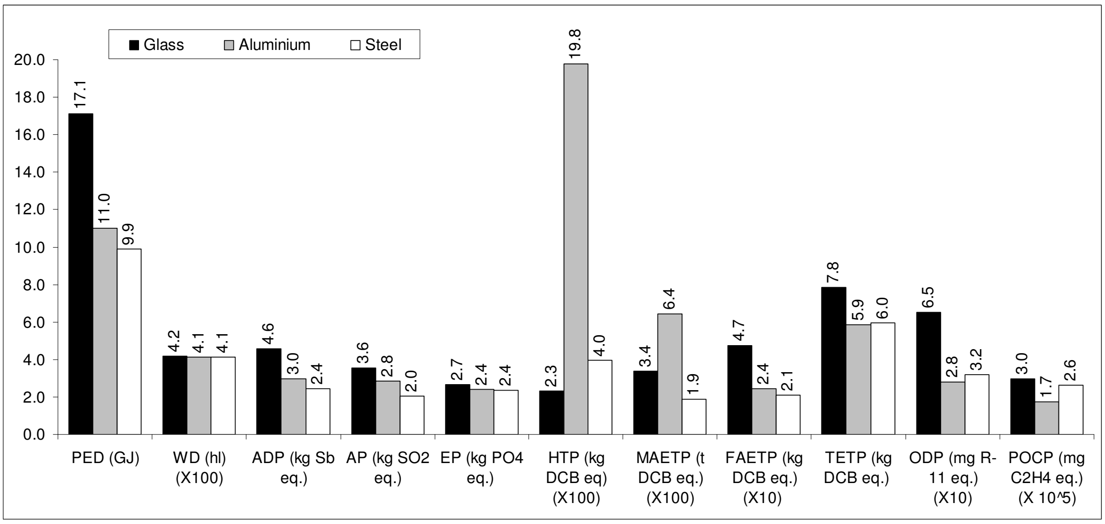

Figure 5-6 Environmental impacts (other than GWP) in the life cycle of beer
[*PED* primary energy demand, *WD* water demand, *ADP* abiotic depletion potential, *AP* acidification potential, *EP* eutrophication potential, *HTP* human toxicity potential, *MAETP* marine aquatic ecotoxicity potential, *FAETP* freshwater aquatic ecotoxicity potential, *TETP* terrestrial ecotoxicity potential, *ODP* ozone depletion potential, *POCP* photochemical ozone creation potential. The scaled values should be multiplied with the factor shown in brackets against the relevant impact to obtain the original values.]

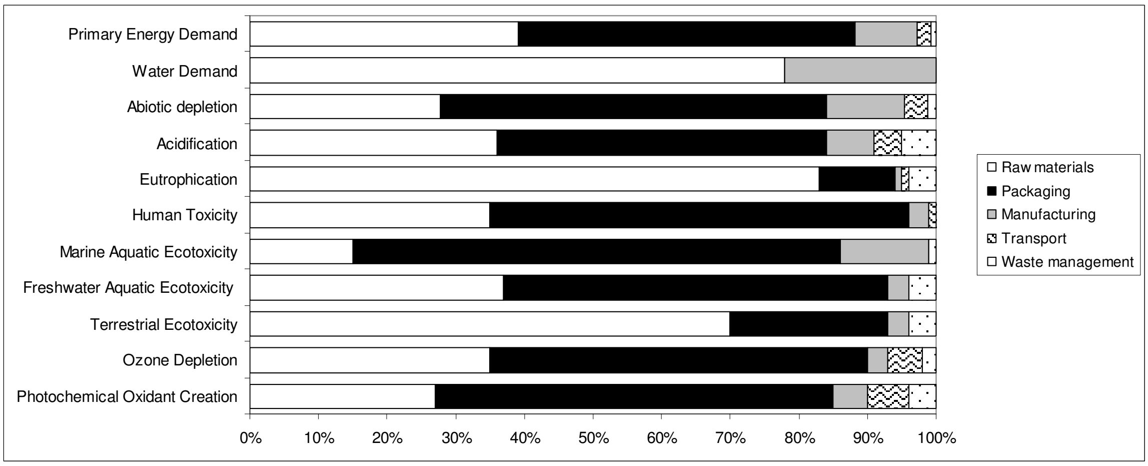

Figure 5-7 Contribution of different life cycle stages to the environmental impacts for the 0.33 l glass bottle

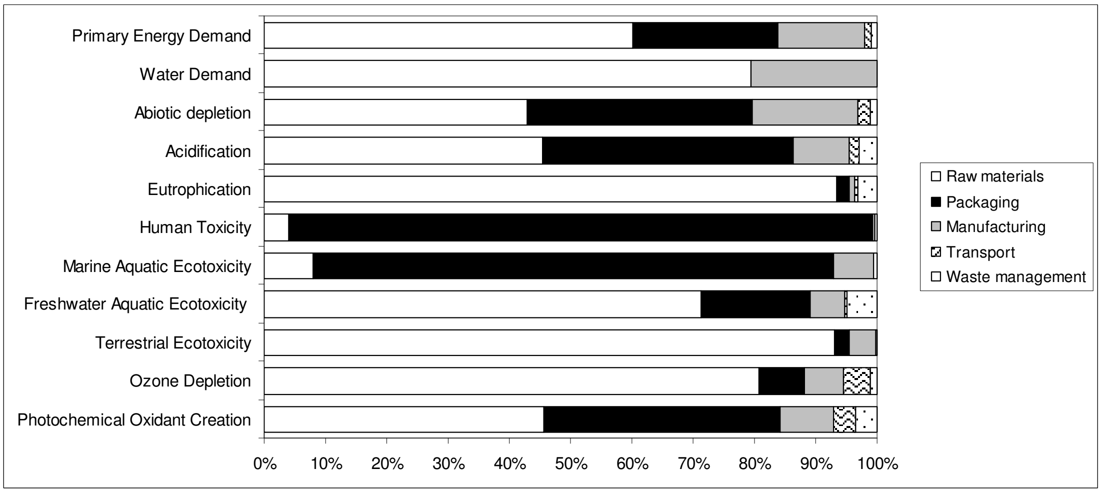

Figure 5-8 Contribution of different life cycle stages to the environmental impacts for the 0.5 l aluminium can

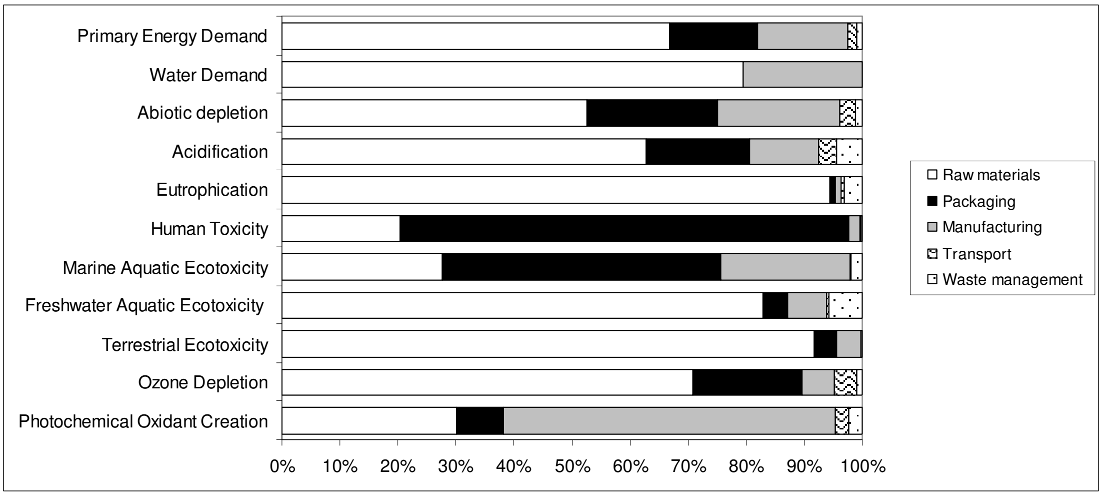

Figure 5-9 Contribution of different life cycle stages to the environmental impacts for the 0.5 l steel can

5.1.3.5 Comparison of environmental impacts for the different packaging options

As observed earlier (section 5.1.2.2), the impact of secondary packaging has not been assessed for the aluminium and steel cans due to lack of data. Therefore, in order to compare the environmental impacts for the different types of packaging on an equivalent basis, an additional analysis considering only the primary packaging has been carried out. The results of this are shown in Figure 5-10. As can be observed from Figure 5-10, the glass bottle is still the least favourable option for ten out of twelve impact categories (including GWP) when the secondary packaging is not taken into account. For example, the GWP of beer packaged in the glass bottle is higher than that of the aluminium and steel cans by factors of 2.4 and 3, respectively.

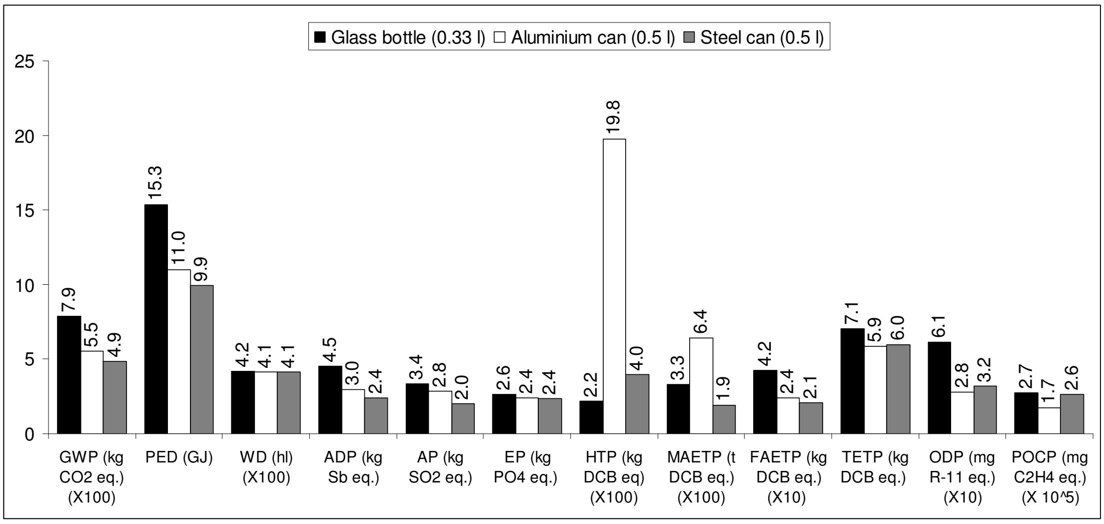

Figure 5-10 Comparison of environmental impacts for the different types of packaging considered in the study
[The scaled values should be multiplied with the factor shown in brackets against the relevant impact to obtain the original values.]

5.1.3.6 Comparison of LCA results with other studies

The results for global warming, primary energy demand, acidification and eutrophication potentials (per 1,000 litres of beer) have been compared in Figure 5-11 to three other studies found in literature (Narayanaswamy et al., 2004; Climate Conservancy, 2004; Kägi et al., 2011). As can be seen, significant variations in the environmental impacts exist. These variations may be attributed to varying agricultural practices and the fact that the beer is produced in different geographical regions. For example, the studies by Narayanaswamy et al. (2004), Climate Conservancy (2004) and Kägi et al. (2011) consider beer production in Australia, USA and Switzerland, respectively. This is a crucial factor as different regions have unique soil types and climate, operate at different production scales and efficiency, and have different energy mixes. Thus, it is not always possible to make direct comparisons among LCA studies. However, the close agreement between the GWP results in the current study and the study by Kägi et al. (2011) can be explained by the fact that both studies are based on primary production data from the same brewing company. The results shown are aimed at highlighting the range of figures that may be obtained for the environmental impacts in the life cycle of beer.

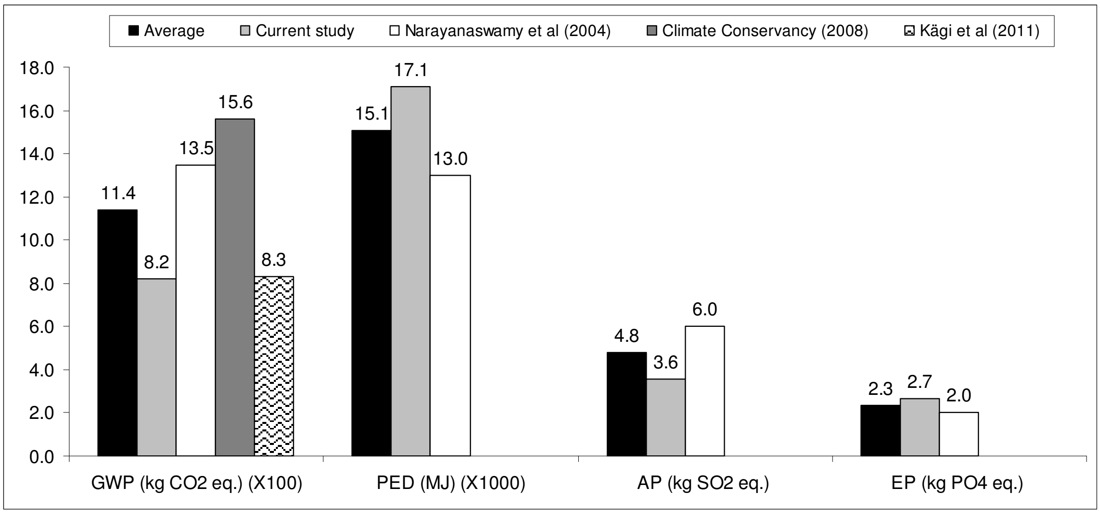

Figure 5-11 Comparison of environmental impacts with other studies
[The scaled values should be multiplied with the factor shown in brackets against the relevant impact to obtain the original values.]

5.1.3.7 Environmental impacts at the sectoral level

In order to estimate the life cycle environmental impacts from the UK beer sub-sector, the results of this study have been extrapolated to the total consumption of 2.1 billion litres from the off-trade (take-home) market in 2010 (Key Note, 2011). Of this amount, 48% and 52% were packaged in bottles and cans, respectively. Considering the volume of beer in the take-home market and consumer penetration by type of packaging, the estimated environmental impacts are shown in Figure 5-12. It can be seen that consumption of beer in the UK was responsible for about 1.4 million tonnes of CO_2 eq. emissions in 2010. This represents about 0.24% of the total UK emissions in 2010[18]. Although the estimates are not directly comparable as in one case they represent the life cycle emissions (beer sector) and mainly direct emissions (total UK emissions), they are nevertheless an indication of the significance of the sectors contribution to the total GHG emissions. While it is difficult to put the other environmental impacts in context (due to the lack of studies focusing on these impacts), it is envisaged that this study could serve as a starting point or reference for future studies on environmental impacts in the beer sector.

It can also be observed in Figure 5-13 that the abiotic depletion, freshwater ecotoxicity and ozone depletion potentials are disproportionately higher for the glass

[18] UK GHG emissions in 2010 are estimated at 582.4 million tonnes CO_2 eq. (DECC, 2011).

bottles than the cans despite its marginally lower market share. This is due to the high consumption of primary energy resources (crude oil and natural gas), high emissions of heavy metals (vanadium, nickel and copper) and emissions of non methane volatile organic compounds (NMVOC), respectively. The cans, on the other hand, contribute a much higher human toxicity potential than their market share would suggest due to the high emission of polyaromatic hydrocarbons.

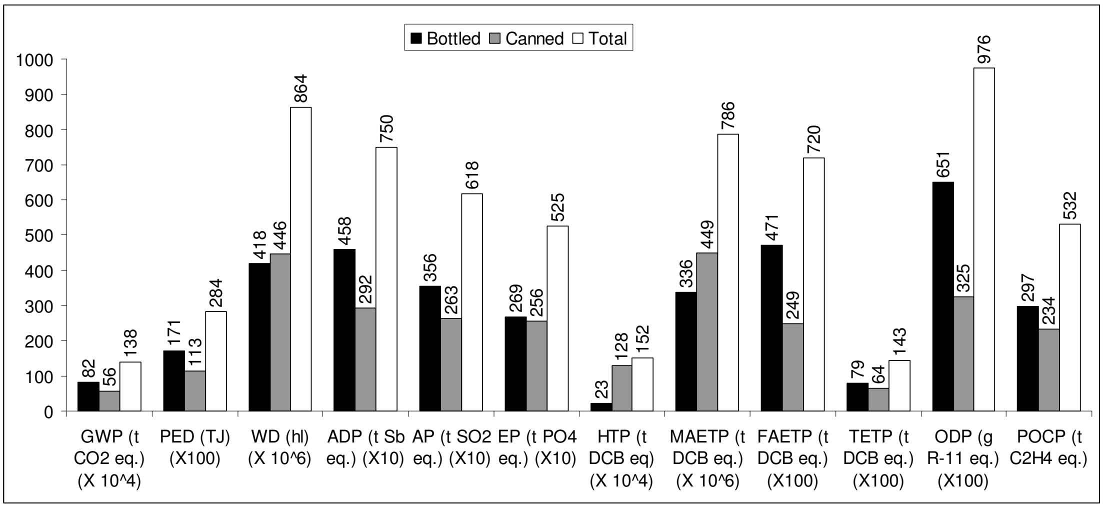

Figure 5-12 Life cycle environmental impacts of beer in the UK
[Impacts from canned beer are estimated based on the average environmental impacts from aluminium and steel cans due to lack of data on the specific fractions of aluminium and steel cans in the UK market. The scaled values should be multiplied with the factor shown in brackets against the relevant impact to obtain the original values.]

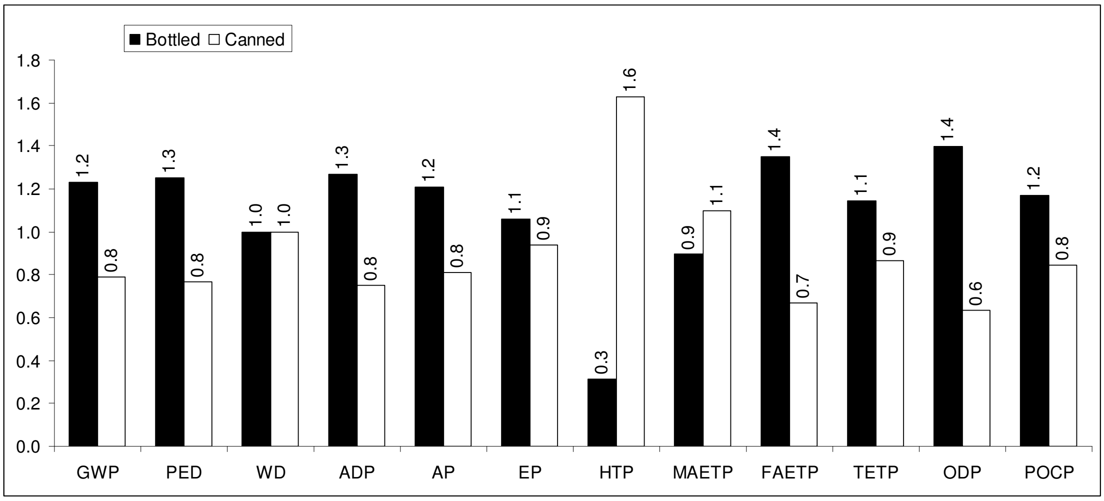

Figure 5-13 Comparison of environmental impacts for different types of packaging relative to their market share

[The values represent the ratio of the impact for each packaging type and its market share of 48% for glass bottles and 52% for cans (it has not been possible to obtain data on the fraction of aluminium and steel cans).]

5.1.3.8 Impact of recycled glass on the environmental impacts

In the UK beer sector, increasing the recycled content of glass bottles has been identified as a key strategy for improving sustainability (Dalton, 2011). In order to assess the impact of recycled content on the environmental impacts in the life cycle of beer, a number of scenarios for a range (0-100%) of recycled contents have been assessed. The impact of recycled content is shown in Figure 5-14 and Figure 5-15 for the GWP and other environmental impacts, respectively.

The results for GWP (Figure 5-14) show that the GWP could be reduced by about 3% or 24 kg CO_2 eq. per functional unit for a 10% increase in the amount of recycled glass. The savings in GWP arise from the packaging and waste management stages due to reduced energy consumption for manufacturing of bottles and reduced packaging waste sent to landfill. A 10% increase in the recycled content also results in savings in other impact categories ranging from 0.4% (EP) to 2% (ADP). Although the environmental savings do not appear significant, this is quite significant at the sectoral level (see Figure 5-15). For example, 3% savings in the GWP amounts to around 24,000 tonnes of CO_2 eq. emissions per year. Thus there is a case for increasing the recycled content of glass bottles in order to reduce the environmental impacts from the beer sub-sector.

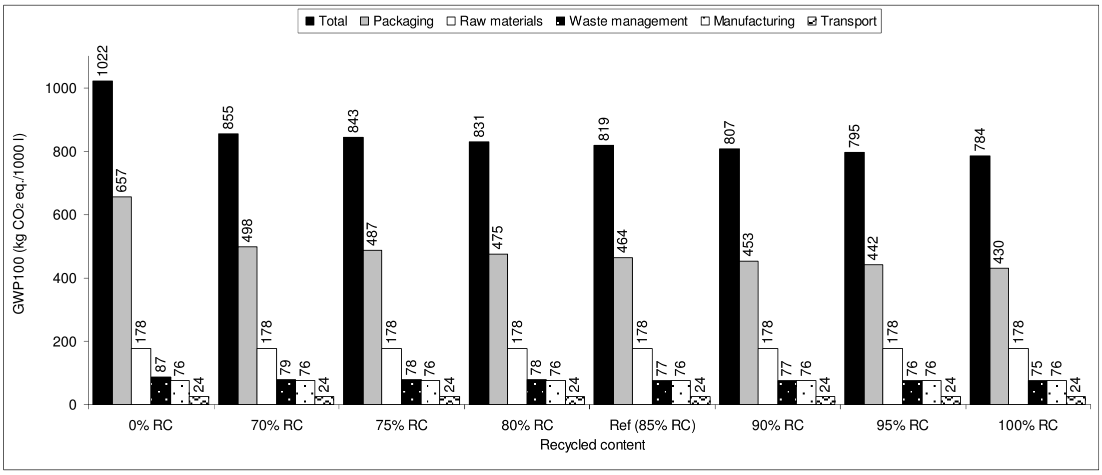

Figure 5-14 Impact of recycled content on global warming potential for the 0.33 l glass bottle

[RC – recycled content; 0% RC - virgin glass, 100% RC – 100% recycled glass cullet. Ref (85% RC) – reference scenario considered in the study]

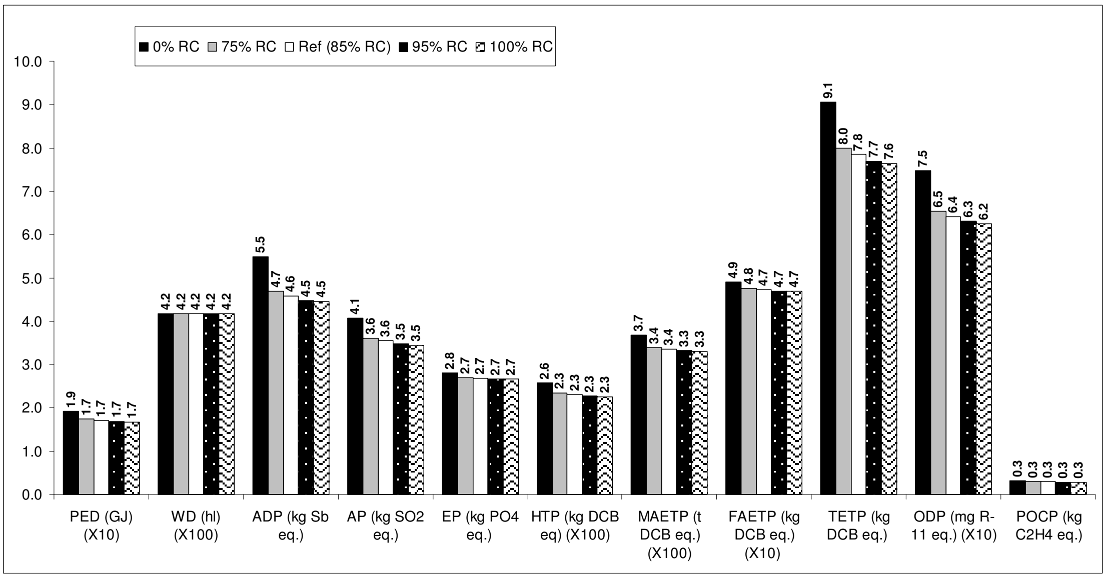

Figure 5-15 Impact of recycled content on the environmental impacts for the glass bottle

[The scaled values should be multiplied with the factor shown in brackets against the relevant impact to obtain the original values.]

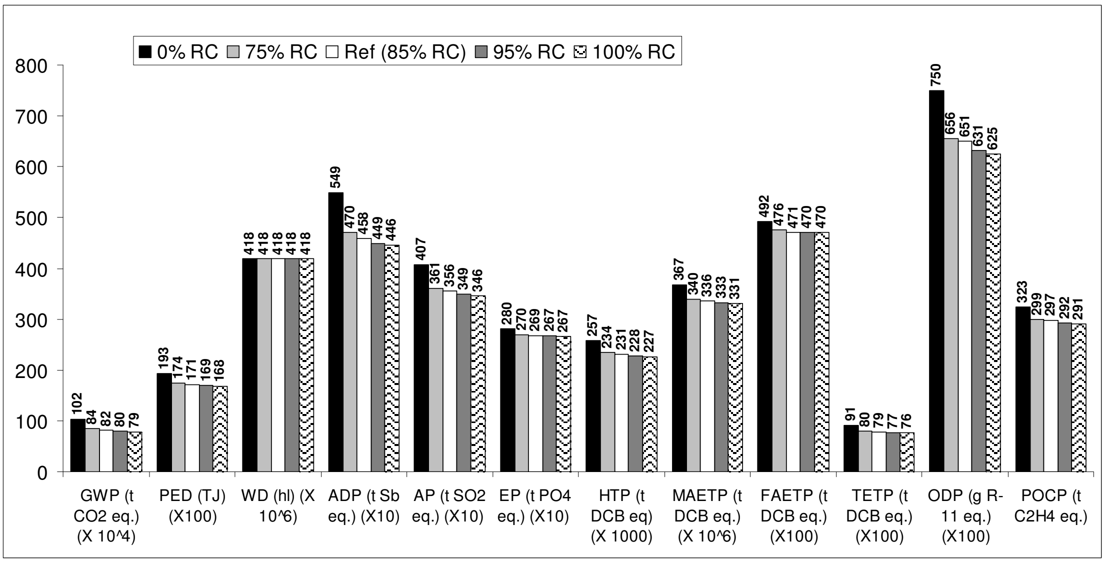

Figure 5-16 Impact of recycled content on the environmental impacts at the sectoral level for the glass bottle

[The scaled values should be multiplied with the factor shown in brackets against the relevant impact to obtain the original values.]

5.1.3.9 Impact of lightweighting on the environmental impacts

In addition to increasing the recycled content, lightweighting has become a key area of focus for innovation in beverage packaging (Cakebread, 2011). Environmental improvements in the area of GHG emissions and resource efficiency (through material savings) have been documented by several multinational brewers including Anheuser-Busch InBev and Heineken UK with figures ranging from 7% to 25% weight reductions reported in the beer sector (WRAP, 2011). In the current study, scenarios for 0% to 30% reductions have been assessed with regard to the environmental impacts. The results are shown in Figure 5-17 to Figure 5-18.

The results in Figure 5-17 show that reducing the glass content by 10% results in GWP savings of around 5% or 40 kg CO_2 eq. per 1,000 litres. The savings in GWP arise from the packaging and transport stages due to reduced energy demand for manufacturing of bottles and reduction in the weight of the packaged product transported to retail. A 10% reduction in the bottle weight also results in savings in other impact categories ranging from 0.5% (EP) to 6.8% (MAETP). The resulting impact savings are quite significant at the sectoral level as illustrated in Figure 5-19. For example, 5% savings in the GWP amounts to around 40,000 tonnes of CO_2 eq.

emissions. Thus there is also a case for the adoption of lightweighting as a strategy for improving the environmental performance in the beer sector.

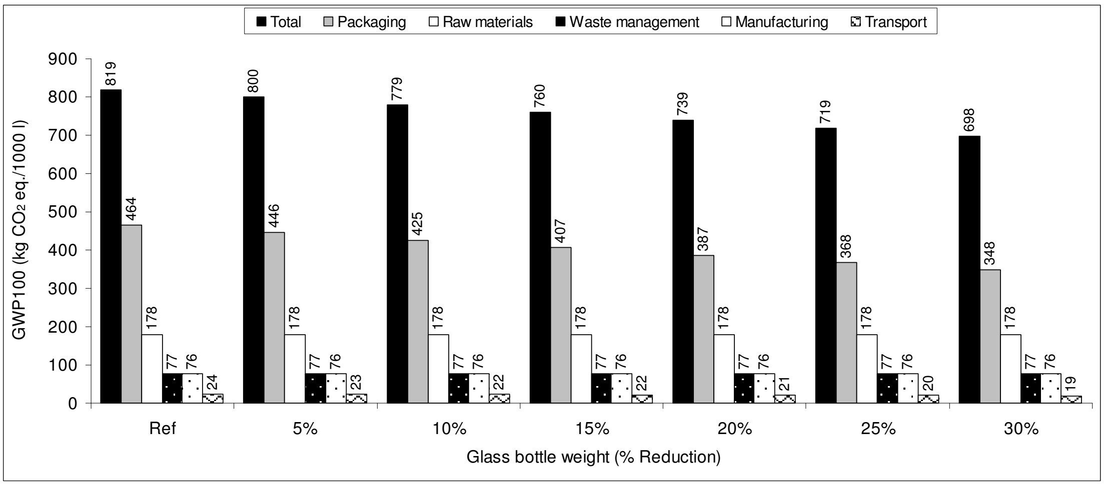

Figure 5-17 Impact of lightweighting on global warming potential (glass bottles)

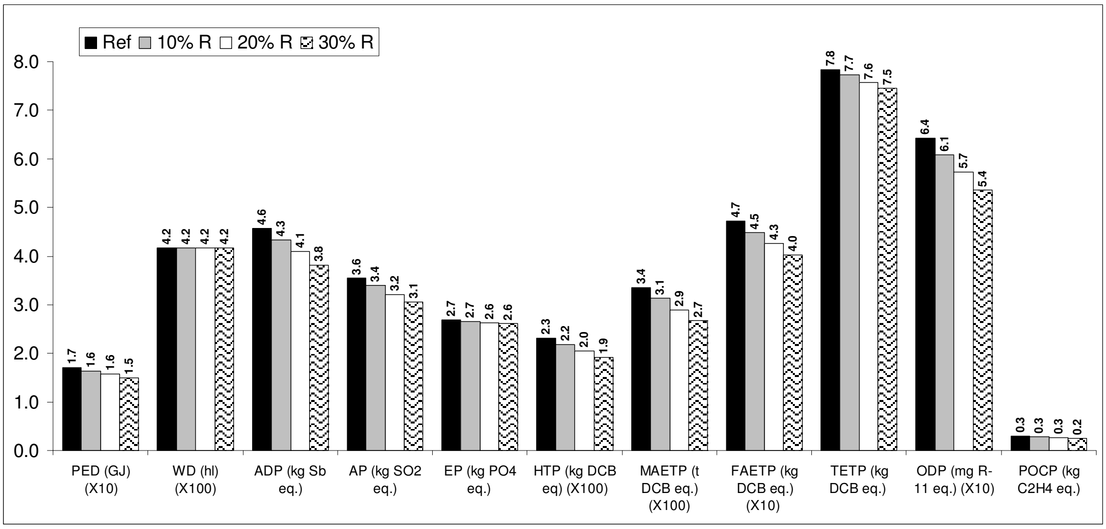

Figure 5-18 Impact of lightweighting on the other environmental impacts (glass bottle)

[The scaled values should be multiplied with the factor shown in brackets against the relevant impact to obtain the original values.]

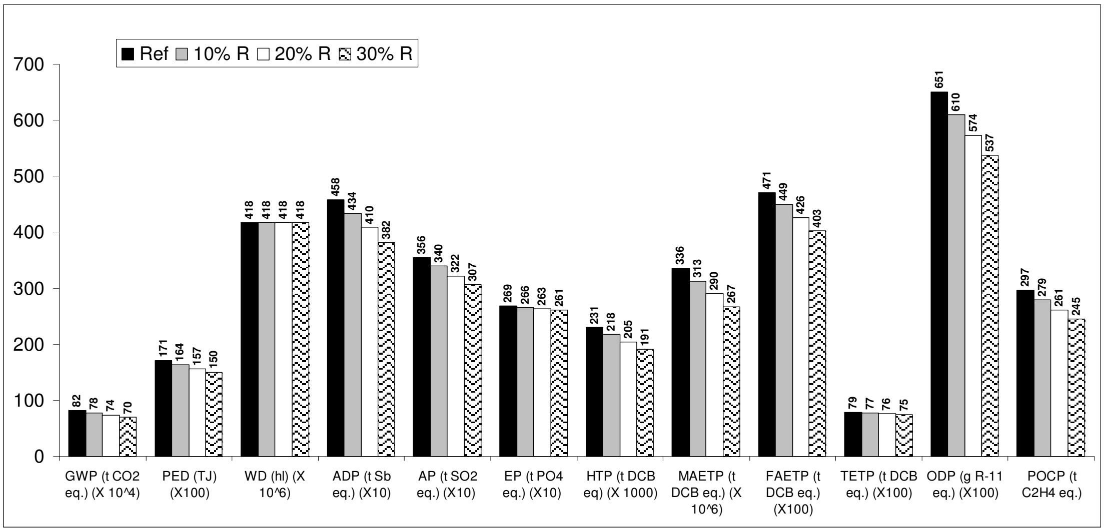

Figure 5-19 Impact of lightweighting on the environmental impacts at the sectoral level (glass bottles)

[The scaled values should be multiplied with the factor shown in brackets against the relevant impact to obtain the original values.]

5.1.3.10 Impact of organic barley on the environmental impacts

As mentioned earlier, the performance of conventional and organic barley has been compared with regard to the other environmental impacts. As can be seen in Figure 5-20, organic barley performs better than conventional barley in 7 out of 10 impact categories (FAETP, HTP, MAETP, POCP, ODP, ADP and water consumption). On the other hand, conventional barley performs better with regard to AP, EP and TETP. The study by Williams et al. (2006) also shows advantages for conventional field-based agricultural commodities with regard to AP and EP. Regarding the issue of resource depletion, the same study found that conventional production requires around 50% more primary energy (for fertiliser production, cultivation and harvesting) while using only a third of the land area required for organic production. Similarly, organic production shows clear advantages with regard to ADP and water consumption (see Figure 5-20). It is important to note however, that the findings from different studies are sensitivity to factors such as methodological choices (system boundaries, allocation methods), crop yields, co-products and how they are utilised, as well as region-specific factors such as local climate and soil types. Therefore, these results have to be interpreted with care although the results in Figure 5-5 and Figure 5-20 suggest that there is a case for using organic barley in the beer supply chain. However, the economic and social implications (not assessed due to lack of data) of sourcing organic barley have to be investigated in order to identify any potential trade-offs before final recommendations can be made.

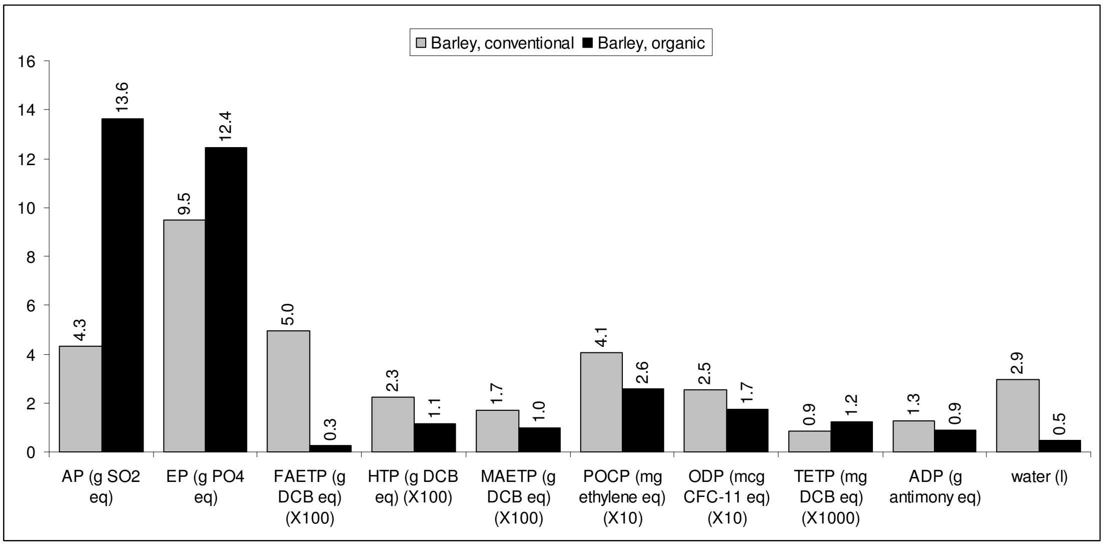

Figure 5-20 Impact of organic barley on the environmental impacts per kg of barley

[The scaled values should be multiplied with the factor shown in brackets against the relevant impact to obtain the original values. The life cycle impact assessment data represents conventional and organic barley produced in Switzerland. Data from the Ecoinvent (2010) database.]

5.1.3.11 Impact of raw materials transport on the environmental impacts

As observed earlier in section 5.1.2.5, transport of the raw materials (other than barley) has not been taken into account due to lack of primary production data. However, an additional analysis has been carried out to estimate the impact of raw materials transport assuming delivery by 40 t trucks over an average distance of 100 km. The analysis showed that, for the different types of packaging, raw materials transport adds less than 1% to all environmental impact categories. This suggests that transport is not an important contributor to the environmental impacts in the life cycle of beer (lager).

5.2 Life cycle economic assessment

Two economic aspects have been considered in the current study: life cycle costs and value added. The methodology follows that used for the LCA as far as possible; further details on the LCA and VA methodologies can be found in Chapter 3. The life cycle costs are considered from the perspective of the producer, consumer and the government.

5.2.1 Goal and scope of the LCC

The current LCC case study has four main goals:

i. to estimate the life cycle costs and value added and identify the hot spots in the life cycle of beer produced and consumed in the UK;
ii. to analyse how the economic aspects may be affected by the type and size of different packaging used in the UK: glass bottles (0.33 l), aluminium cans (0.5 l) and steel cans (0.5 l);
iii. to estimate the life cycle costs and value added from the beer sub-sector based on the findings from the first two goals of the case study and a UK market analysis; and
iv. to estimate the impact of improvement options on the life cycle costs and value added.

Similar to the LCA, the functional unit is based on 1,000 litres of beer while the sectoral analysis considers total annual production and consumption of beer in the UK. The system boundary is also from 'cradle to grave', comprising the life cycle stages detailed earlier in the LCA.

5.2.2 Inventory data and assumptions

The life cycle inventory data are based on the LCA data presented in section 5.1.2. Primary production cost data have been obtained from literature, including the costs of raw materials for production of beer, the amounts of primary and secondary packaging materials, and utilities consumed at the manufacturing stage. It is assumed that freight costs are included in the costs of materials; therefore the cost impact for each material in the life cycle includes transport. It is also assumed that the manufacturer bears the costs for raw materials, utilities for manufacturing, wastewater treatment of effluents from the brewery and freight of raw materials, while the consumer bears the costs for disposal of post-consumer waste packaging through taxes paid for waste disposal services. More detail on the cost data are provided below.

5.2.2.1 Raw materials

The sources for the costs of the main raw materials for beer production are summarised in Table 5-8. The cost for water supply has been sourced from the public utility while the cost for barley has been sourced from the international commodity market and may not accurately reflect prices in the UK.

Table 5-8 Costs of raw materials in the life cycle of beer

Raw materials and utilities	Cost (£/1000 l)	Source of cost data
Barley	10.2	Indexmundi.com (2011)
Water	8.4	United Utilities (2010)
Sodium hydroxide	0.5	IChemE (2002)
Phosphoric acid	0.6	ICIS (2010)
Sulphuric acid	0.1	ICIS (2010)
Carbon dioxide	2.2	Confidential
Light fuel oil	13.1	OECD (2007)
Hops	45.0	The Home Brew Shop (2008)

5.2.2.2 Packaging

The costs of packaging materials are summarised in Table 5-9. It is important to note that the material costs shown do not include the costs associated with fabrication of the specific type of packaging (bottles, cans and crates) due to lack of data (confidentiality).

Table 5-9 Costs of packaging materials in the life cycle of beer

Packaging type	Cost (£/1000 l)	Source of cost data
Glass bottles (0.33 l)		
Primary glass (15% content)[a]	48.7	Aliexpress.com (2010)
Recycled glass cullet (85% recycled content)[b]	4.9	WRAP (2011)
Steel (closure)[e]	2.1	LME (2011)
Cardboard (multi pack crate)	4.0	WRAP (2011)
Aluminium cans (0.5 l)		
Primary aluminium (58% content)[c]	48	LME (2011)
Recycled aluminium (42% recycled content)[d]	14.9	Letsrecycle.com (2010)
Steel cans (0.5 l)		
Primary steel (can body; 38% content)[e]	10.3	LME (2011)
Recycled steel (can body; 62% recycled content)[f]	7.0	Letsrecycle.com (2010)
Primary aluminium (52% content of can end)[c]	4.0	LME (2011)
Recycled aluminium (can end; 48% recycled content)[d]	29.4	Letsrecycle.com (2010)

[a]Price per kg of coloured container glass.
[b]Average price of recycled green glass cullet in the UK.
[c]Seller price of high grade primary aluminium in the commodity market.
[d]Market price for baled used aluminium cans in the UK market.

[e]Seller price of steel in the commodity market.
[f]Market price for baled used steel cans in the UK market.

5.2.2.3 Manufacturing

The main process stages in beer production and the utilities required are summarised in section 5.2.3. The cost data for the manufacturing stage are summarised in Table 5-10. Utilities including steam and compressed have not been taken into account due to lack of data.

Table 5-10 Costs of manufacturing inputs in the life cycle of beer

Energy/material	Cost (£/1000 l)	Source of cost data
Electricity	17.0	Electricityprices.org.uk (2011)
Yeast	1.8	The Home Brew Shop (2008)
Brewery effluent treatment	14.0	Scottish Water (2011)

5.2.2.4 Waste management (post-consumer)

The waste disposal costs for post-consumer waste packaging are summarised in Table 5-11. It has been assumed that the non-recycled fraction of the glass bottle, aluminium cans and steel cans, as well as the steel closures and cardboard crates are sent to landfill at the end of life.

Table 5-11 Costs of waste management options in the life cycle of beer[a]

Waste	Cost (£/1000 l)	Waste management
Glass bottle (0.33 l)		
Glass bottles	7.3	15% landfilled
Steel closures	0.5	Landfilled
Cardboard crates	3.7	Landfilled
Aluminium can (0.5 l)		
Aluminium can body	1.3	58% landfilled
Aluminium can ends	0.3	58% landfilled
Steel can (0.5 l)		
Steel can body	2.0	38% landfilled
Aluminium can ends	0.2	52% landfilled

[a]All cost data from WRAP (2010)

5.2.2.5 Consumer costs

As earlier observed in section 5.2.2, it has been assumed that the consumer bears the costs of disposal of packaging waste arising after consumption through taxes paid for waste disposal services. These are shown as costs for landfill of packaging materials in Table 5-11. The retail price of the product which has been used to estimate value added, can also be classified as consumer costs. The retail prices are given in Table 5-12.

Table 5-12 Average retail price of beer in the UK market

Type of packaging for product	Average UK retail price (£/1000 l)[a]
Glass bottle (0.33 l)	3,238
Aluminium can (0.5 l)	2,419
Steel can (0.5 l)	2,536

[a]Data based on the average retail price of beer packaged in glass bottles (0.33 l), aluminium cans (0.5 l) and steel cans (0.5 l) in the major UK retail outlets: Asda, Tesco and Sainsbury's. Data accessed 25 July 2011.

5.2.2.6 Data quality

Using the data quality assessment approach presented in Chapter 3, the LCC data quality has been assessed. The overall LCC data quality as been assessed as 'Medium' for the different packaging systems considered in the study. More detail on the data quality assessment is provided in Appendix 4, section A4.2.

5.2.3 Life cycle economic impacts and interpretation

The results of the LCC are discussed first, followed by the VA results. Following this, these two economic aspects are discussed for the beer sub-sector.

5.2.3.1 Life cycle costing (LCC)

The results of the LCC are shown in Figure 5-21. The LCC results shown represent the production costs of beer accrued to the manufacturer, excluding the costs for disposal of post-consumer packaging waste. However, post-consumer waste disposal costs account for 5% of the total LCC for the glass bottles and 1% for the aluminium and steel cans. The highest LCC (£217 per 1,000 l beer) is found for the glass bottle and the lowest (£183) for the steel can. Beer packaged in the aluminium can has the LCC of £204 per functional unit.

As can be seen from Figure 5-21, the raw materials stage is the major hot spot in the life cycle of beer, accounting for 58%, 62% and 69% of the LCC for beer packaged in the glass bottle, aluminium and steel can, respectively. This is mainly due to water for cultivation of barley (£45.4 per 1,000 l beer), accounting for 36% of the total cost of raw materials. Water for production of beer and other auxiliary uses also accounts for around 7% of the LCC from the raw materials stage.

The contribution to LCC from packaging ranges from 13% (steel can) to 27% (glass bottle), while it accounts for 22% of the LCC for the aluminium can. Manufacturing, on the other hand, accounts for 15%, 17% and 18% of the LCC for the glass bottle, aluminium can and steel can, respectively. The LCC from manufacturing is mainly (51%) due to electricity consumption in the brewery.

Figure 5-21 Life cycle costs of beer for different types of packaging also showing the contribution of different life cycle stages

[The life cycle costs are shown from the manufacturer's perspective. Costs for disposal of post-consumer packaging waste, accounting for 5% for the glass bottles and 1% for the aluminium and steel cans, are not included as they are borne by the consumer through taxes paid for waste disposal services.]

5.2.3.2 Value added

The results for value added (VA) accrued to the manufacturer are shown in Figure 5-22. The VA represents the difference between the retail prices and the LCC. The average retail price of beer for the different types of packaging has been estimated based on retail prices in the major retail outlets in the UK as shown in Table 5-12. As can be seen, beer packaged in glass bottles has the highest VA (£3,021 per 1,000 l) despite having the highest LCC. The lowest VA is observed for the aluminium can

(£2,215 per 1,000 l) while beer packaged in the steel can has the VA of £2,353 per functional unit, representing significant revenues for the producer.

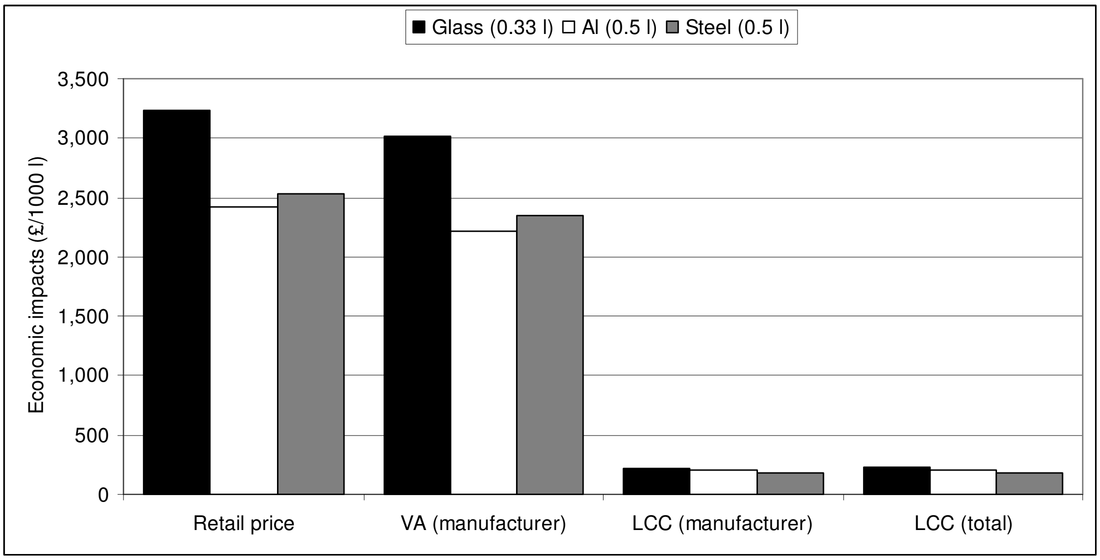

Figure 5-22 Value added of beer for different types of packaging per 1000 litres of beer also showing the retail prices and life cycle costs

[VA (manufacturer) – value added accrued by the manufacturer. LCC (manufacturer) – life cycle costs for the manufacturer (minus costs for disposal of post-consumer packaging waste. LCC (total) – total life cycle costs including disposal of post-consumer packaging waste.]

5.2.3.3 Life cycle costs and value added at the sectoral level

Similar to the LCA, the economic impacts from the UK beer sub-sector have been estimated by extrapolating the LCC and VA results for the total consumption of 2.1 billion litres from the off-trade market in 2010 and the market shares for the different types of packaging (48% in bottles and 52% in cans). Considering the total consumption and consumer penetration by type of packaging, the LCC and VA for the beer sub-sector are shown in Figure 5-23. It can be seen that beer production and consumption in the UK was responsible for over £440 million in life cycle costs in 2010. The VA from the beer sector for the reference year is estimated to be about £5.6 billion. This amounts to approximately 0.4% of the UK Gross Domestic Product (GDP)[19], demonstrating the significance of the life cycle economic impacts of the beer sector in the UK.

[19] Based on the stated UK GDP of £1,392,634 million for 2009 (Key Note, 2011: sourced from Economic and Labour Market Review, November 2010, National Statistics website.

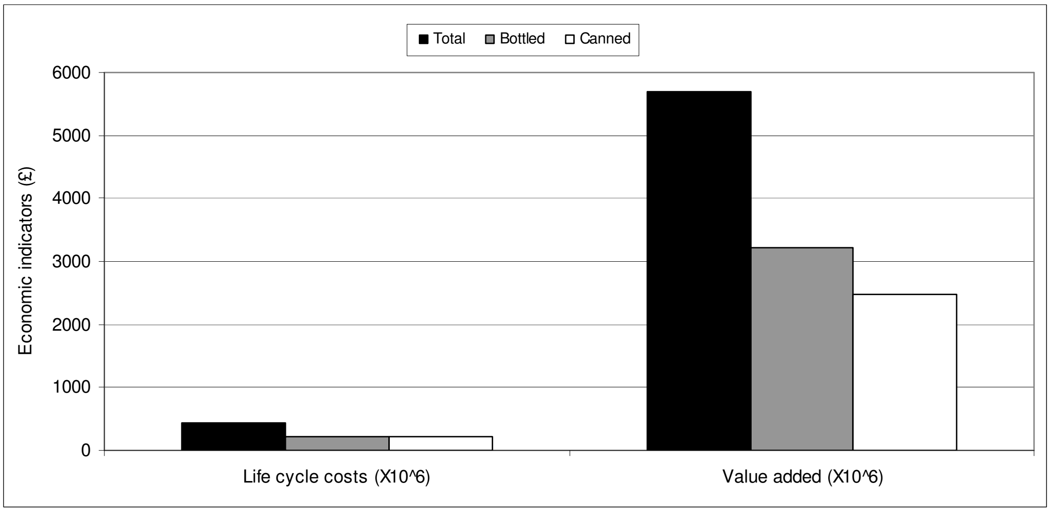

Figure 5-23 Economic impacts of beer consumption in the UK

5.2.3.4 Impact of recycled content on the economic aspects

As part of the sensitivity analysis, the impact on the LCC and VA of increasing the recycled content of the glass bottles has been assessed. The results in Figure 5-24 show that increasing the recycled content of glass bottles by 10% would reduce the LCC by about 14% and increase the VA by about 1% for the manufacturer. At the sectoral level, this amounts to the LCC savings and increasing the VA of about £31 million annually[20].

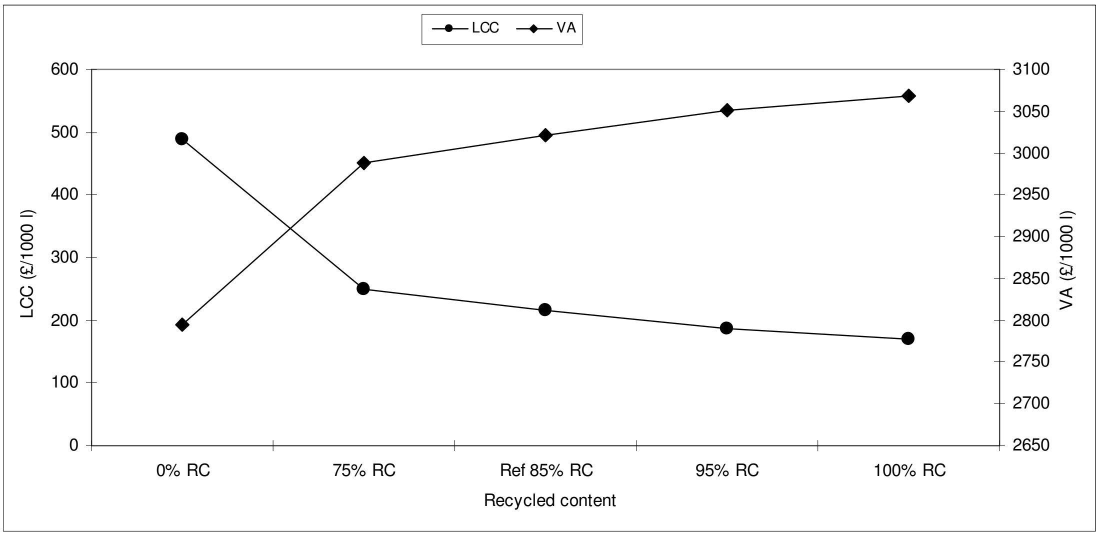

Figure 5-24 Impact of recycled content on the life cycle costs and value added per 1000 litres of beer (0.33 l glass bottle)

[20] Based on the estimated consumption of ~1 billion litres of beer packaged in glass bottles.

5.2.3.5 Impact of lightweighting on the economic aspects

The effects of lightweighting on the LCC and VA have also been assessed as part of the sensitivity analysis. The results in Figure 5-25 indicate that 10% reduction in the bottle weight results in LCC savings and increase in VA of around 2% and 0.2%, respectively. The savings are mainly due to reduced costs of packaging materials. It is pertinent to note that the analysis does not account for costs associated with research and development and any equipment modifications due to lack of data. However, the findings suggest that lightweighting is potentially beneficial to the manufacturer from an economic perspective.

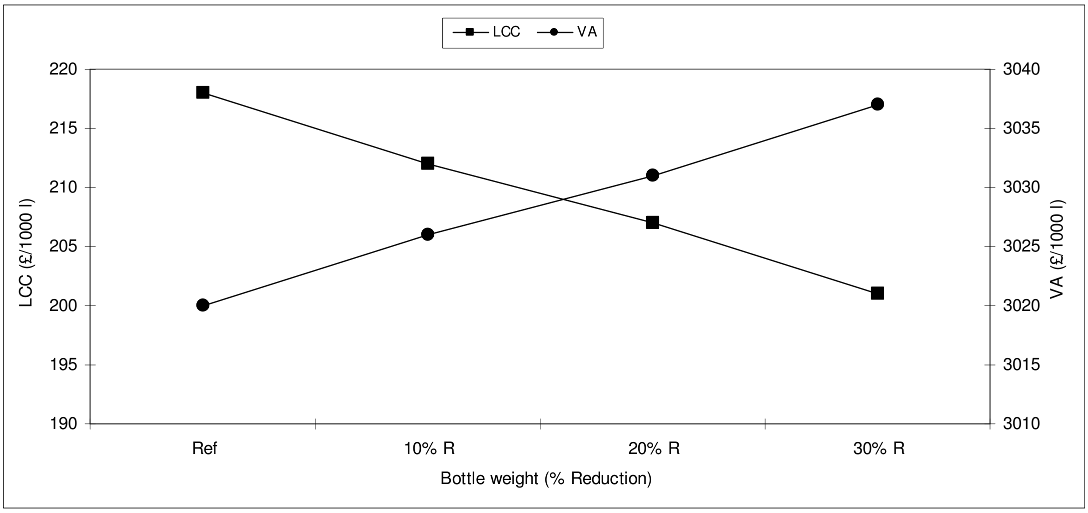

Figure 5-25 Impact of lightweighting on the life cycle costs and value added per 1000 litres of beer (0.33 l glass bottle)

5.3 Comparison of environmental and economic sustainability

As shown in section 5.1.3.1, the glass bottle is the least preferred packaging option with regard to the GWP, with the total GWP estimated as 819 kg CO_2 eq./1,000 l. The 0.5 l steel can, on the other hand, is the most advantageous option with a total GWP of 487 kg CO_2 eq./1,000 l, while the aluminium can has the GWP of 551 kg CO_2 eq./1,000 l. Similar to the GWP, the glass bottle is the least preferred option for nine other environmental impacts categories (PED, WD, ADP, AP, EP, FAETP, TETP, ODP and POCP), while the aluminium can is the worst option for HTP and MAETP. The analyses in sections 5.2.3.1 and 5.2.3.2 also show that the glass bottle is the least preferred option for the LCC, while it also accounts for the highest VA.

The contributions of the different life cycle stages to the environmental and economic impacts are shown in Figure 5-26 to Figure 5-28 for the different packaging options considered. It can be seen that the raw materials and packaging stages are the major contributors to the environmental impacts and life cycle costs for all packaging options. The manufacturing stage is also an important contributor to POCP for the steel can. Overall, the results of the LCA, LCC and VA suggest that the glass bottle is the least environmentally sustainable option. However, it accounts for a significantly higher contribution to VA from the beer sub-sector despite accounting for 48% in terms of consumer penetration in the take-home market. The results of the LCA and LCC also suggest that the steel can is the most sustainable option from an environmental and cost perspective. The results in Figure 5-29 and Figure 5-30 also demonstrate that increasing the recycling content and lightweighting of the bottles are viable options for improving the environmental and economic sustainability performance in the beer supply chain.

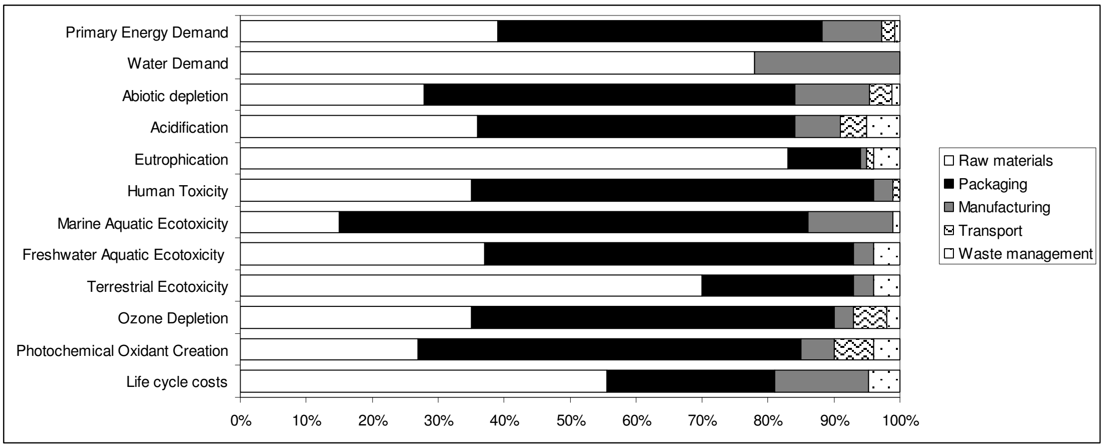

Figure 5-26 Contribution of different life cycle stages to the environmental and economic impacts for the glass bottle

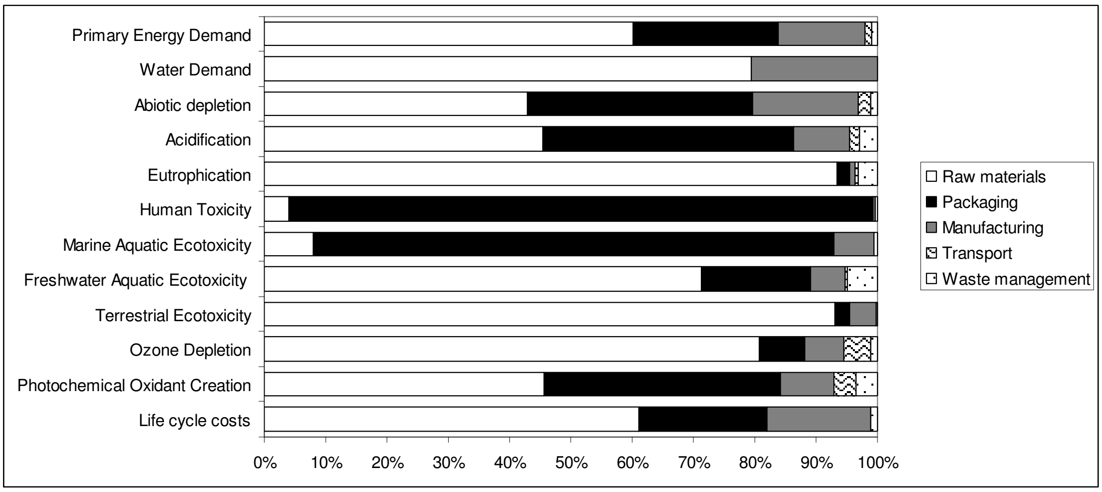

Figure 5-27 Contribution of different life cycle stages to the environmental and economic impacts for the aluminium can

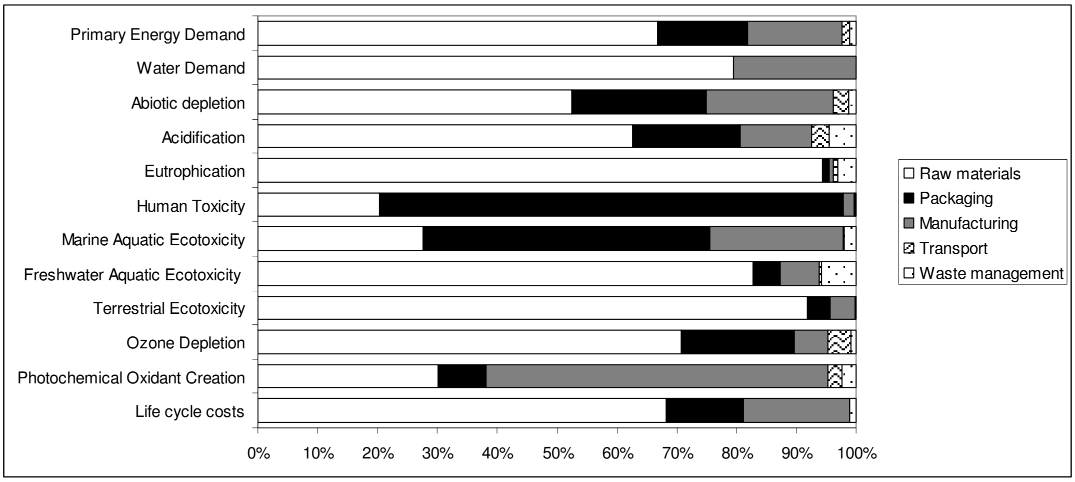

Figure 5-28 Contribution of different life cycle stages to the environmental and economic impacts for the steel can

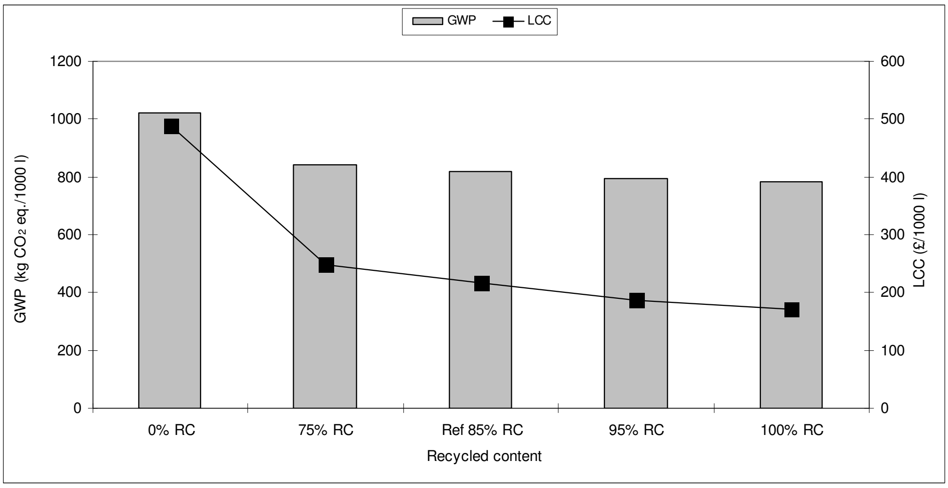

Figure 5-29 Impact of recycled glass on the GWP and LCC

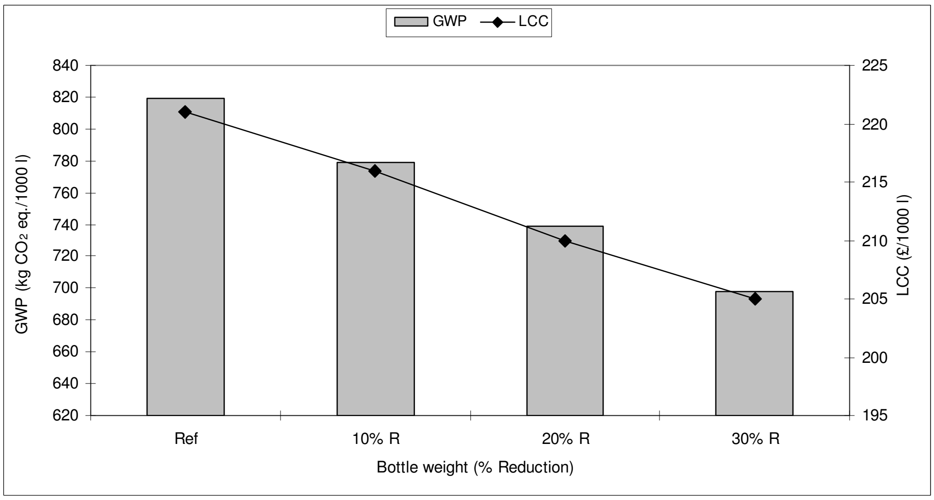

Figure 5-30 Impact of lightweighting on the GWP and LCC

5.4 Summary

The environmental and economic impacts in the life cycle of beer have been quantified using the LCA, LCC and VA analyses. The objectives of the current case study have been met in that:

- the environmental and economic impacts in the life cycle of beer have been estimated considering three packaging options used in the UK: 0.33 l glass bottles, 0.5 l aluminium cans and 0.5 l steel cans;
- the hot spots in the life cycle have been identified for the environmental and economic impacts;

- the life cycle environmental and economic impacts from the beer sub-sector have been estimated based on the findings from the LCA, LCC and a UK market analysis; and
- the impact of improvement options (recycled content and lightweighting) have been estimated for the environmental and economic impacts.

The results of the LCA indicate that beer packaged in steel cans has the lowest environmental impacts for most environmental impact categories including global warming. The glass bottle is the least preferred option for most environmental impacts. The results of the LCA suggest that raw materials and packaging are the major hot spots contributing between 46% – 65% and 23% – 49%, respectively.

The sectoral analysis shows that consumption of beer in the UK was responsible for about 1.4 million tonnes of CO_2 eq. emissions in 2010, taking into account only the volume of beer consumed in the take-home market.

The market analysis also shows that the abiotic depletion, freshwater ecotoxicity and ozone depletion potentials are disproportionately higher for glass bottles than its market share due to the high consumption of energy resources (crude oil and natural gas), high emissions of heavy metals (vanadium, nickel and copper) and emissions of volatile organic compounds, respectively. The cans, on the other hand, contribute a much higher human toxicity potential than their market share due to the emission of polyaromatic hydrocarbons.

Improvement options such as increasing the recycled content and lightweighting of glass bottles are shown to reduce the environmental impacts in the life cycle of beer. For example, a 10% increase in recycled content would reduce the global warming potential by about 3% or 24 kg CO_2 eq. per 1,000 l, amounting to about 24,000 tonnes of CO_2 eq. emissions at the sectoral level. Similarly, a 10% reduction in the weight of the glass bottle results in global warming potential savings of about 5% or 40 kg CO_2 eq. per 1,000 l. This amounts to about 40,000 tonnes of CO_2 eq. emissions at the sectoral level.

The results of the LCC indicate that beer packaged in steel cans has the lowest life cycle costs while the LCC of beer packaged in aluminium cans is also marginally lower than that of beer packaged in the glass bottles. The raw materials stage is the major hot spot for the LCC contributing between 58% - 69%, mainly due to water required for cultivation of barley. Packaging and manufacturing, on the other hand, contribute between 13% - 27% and 15% - 18%, respectively of the LCC.

Based on the results of the LCC, the value added for beer packaged in glass bottles, aluminium cans and steel cans has been estimated as £3,021, £2,215 and £2,353 per 1,000 l, respectively. Value added from the beer sector, based on the results of the case study, are estimated to be about £5.6 billion, amounting to 0.4% of the UK GDP.

The environmental improvement options – increasing the recycled content and lightweighting of glass bottles – are shown to also reduce the LCC and increase VA for the manufacturer in the life cycle of beer. For example, a 10% increase in the recycled content would reduce the LCC by about 14%, while increasing VA by about 1%. At the sectoral level, this amounts to about £31 million. Similarly, 10% reduction in the weight of glass bottles results in LCC savings and VA increase of 2.4% and 0.2% respectively. This amounts to about £5 million at the sectoral level.

A comparison of the contribution of the different life cycle stages to the LCA and LCC results shows that raw materials and packaging are the major contributors to environmental and economic impacts in the life cycle of beer. The results also illustrate the decoupling of environmental and economic impacts from increasing the recycled content and lightweighting of glass bottles.

The next chapter focuses on the environmental and economic sustainability of wine.

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6 LIFE CYCLE ASSESSMENT OF ENVIRONMENTAL AND ECONOMIC SUSTAINABILITY OF RED WINE

The current chapter presents the life cycle assessment of environmental and economic sustainability of Australian red wine in the UK market. Life cycle assessment (LCA) is used to quantify the environmental impacts while the economic impacts are quantified using life cycle costing (LCC) and value added (VA) analysis. A similar analysis is also carried out for the wine sector based on the results of the LCA, LCC, VA and UK market analyses. The results of the LCA are discussed first followed by the results of the LCC and VA analyses.

6.1 Life Cycle Assessment

Similar to the case studies presented in the preceding chapters, the current LCA study follows the LCA methodology as specified in the ISO 14040/44 standards (ISO, 2006a&b). The study starts with the goal and scope definition, followed by inventory, impact assessment and interpretation of results. Various sensitivity analyses are also performed as detailed further below.

6.1.1 Goal and scope of the LCA

The current LCA case study has three main goals:

i. to estimate the environmental impacts and identify the hot spots in the life cycle of wine consumed in the UK;
ii. to estimate the life cycle impacts from the wine sector in the UK based on the findings from the first goal of the case study and a UK market analysis; and
iii. to estimate the effect of potential improvement options in the life cycle environmental impacts.

The focus of the study is red wine produced in Australia for two reasons: firstly, the UK imports of wine from Australia are significant, representing 17% of all wine consumed in the UK; secondly, primary production data were only available for this wine.

For the first goal of the study, the functional unit is based on 1,000 litres of wine. For the sectoral analysis, the functional unit considers total annual consumption of Australian wine in the UK.

The life cycle of wine is shown in Figure 6-1. The system boundary of the study is defined from ‘cradle to grave’, comprising the following life cycle stages:

- ***Raw materials***: water supply, production of fertilisers and pesticides, and production of fuels for cultivation and harvest of wine grapes;
- ***Packaging***: production of primary packaging including glass bottles, cork stoppers, and kraft paper labels;
- ***Manufacturing***: manufacture of wine; production and consumption of electricity, fuels and auxiliary materials including water, sulphur dioxide and sodium hydroxide for production of wine;
- ***Transport***: transport of packaging materials to the winery, bottled wine to the retailer and post-consumer waste packaging to waste management; and
- ***Waste management***: wastewater treatment of effluents from the winery and disposal of in-process and post-consumer waste.

The following activities are excluded from the system boundary due to lack of data:

- transport of raw materials for cultivation and harvest of wine grapes;
- production of secondary packaging materials
- electricity consumption at the retail stage (red wine is normally stored at ambient temperature); and
- transport of consumers to purchase the wine and any storage at consumer.

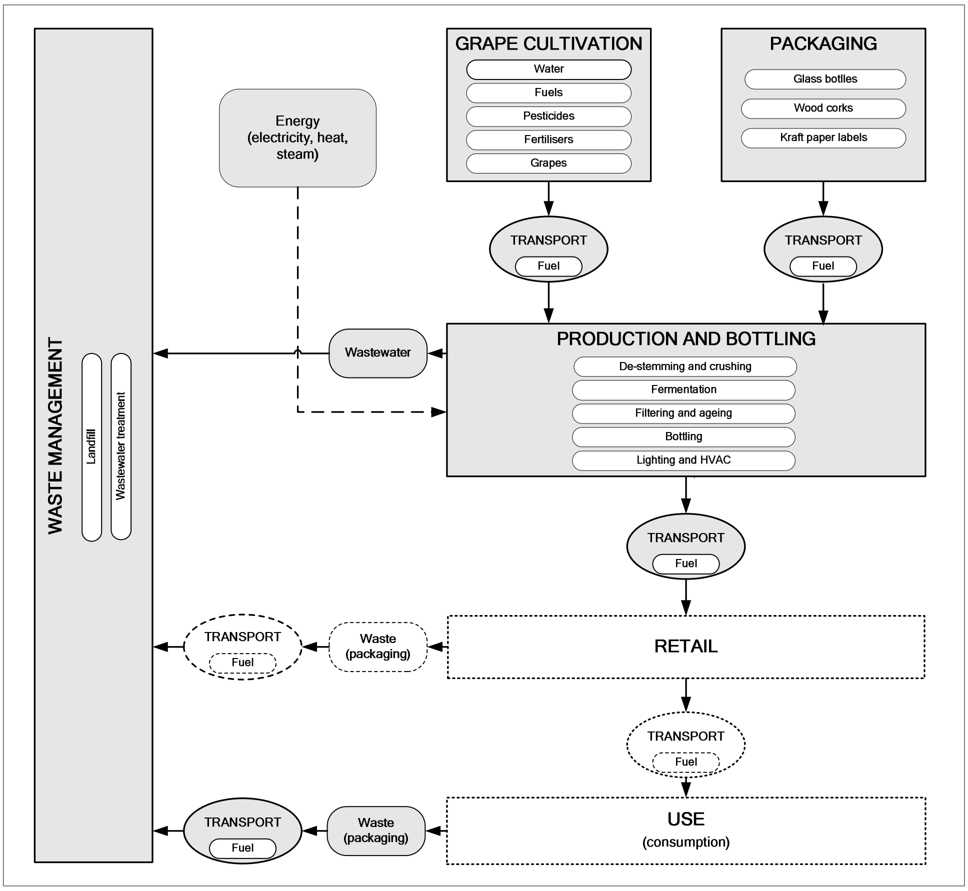

Figure 6-1 The life cycle of wine

6.1.2 Inventory data and assumptions

Primary production data have been obtained from the wine manufacturer, including the amounts of fertilisers, fuels and pesticides for cultivation and harvest of wine grapes; electricity as well as fuel and auxiliary materials for manufacturing of wine. All other data have been sourced from the CCaLC (2011), Ecoinvent (2010) and Gabi (PE, 2010) databases. More detail on the inventory data and their sources is provided below.

6.1.2.1 Raw materials

As shown in Table 6-1, the main raw materials for cultivation and harvest of wine grapes consist of water, fertilisers and pesticides, and fuels (diesel and petrol) for the agricultural machinery. All the raw materials are sourced locally from the Barossa Valley region of South Australia.

Table 6-1 Raw materials for cultivation and harvest of wine grapes[a]

Raw and auxiliary materials	Quantity/ 1000 l
Water	482,625 l
Nitrogen fertiliser	15 kg
Phosphorus fertiliser	37 kg
Pesticides	13 kg
Diesel	9.8 l
Petrol	4.2 l
Wine grapes (output)	*1,400*

[a]All LCI data from the Ecoinvent (2010) database

6.1.2.2 Packaging

The types of primary packaging material are summarised in Table 6-2. The wine is packaged in 0.75 litre bottles using cork stoppers and paper labels. Data on the components and weights of the primary packaging have been obtained from a life cycle-based LCA study on the carbon footprint of beverage packaging in the UK (Gujba and Azapagic, 2010). Limited data are available on the life cycle impacts of glass making in Australia (WRAP, 2007), therefore the glass bottles are assumed to have a recycled content of 85% based on the UK situation for green glass bottles (British Glass, 2007). However, different percentages of recycled glass content are considered in the sensitivity analysis further below. The study also considers the effect of packaging wine in cartons as part of the sensitivity analysis. The components of the carton packaging (cartons and polypropylene tops) are shown in Table 6-2. As mentioned earlier, secondary packaging materials have not been included in the study due to lack of data.

Table 6-2 Components and weights of the primary packaging materials

Packaging type	Weight (kg /1000 l)	Source of LCI data
Glass bottles (0.75 l) (85% recycled content) Cartons (1 l)[b]	620 33	CCaLC (2011) Ecoinvent (2010)
Cork stoppers PP tops[b]	7 1.75	Ecoinvent (2010) CCaLC (2011)
Kraft paper labels	1.4	Ecoinvent (2010)

[a]The sealing foil for the cork stopper has not been considered due to lack of data.
[b]Carton packaging has been considered as part of the sensitivity analysis.

6.1.2.3 Manufacturing

The main process stages in manufacturing of wine are summarised below (Wine Australia, 2011). The manufacturing process begins with de-stemming and crushing of the grapes to obtain a liquid must. Prior to fermentation, the temperature of the must can be adjusted to allow a period of cold maceration. This allows the extraction of compounds from the grape skins which is crucial to red winemaking. The must is then fermented at a temperature of about 28 to 30 degrees Celsius, during which yeast is fed into the fermentation vessel to convert the sugars into alcohol. After fermentation, the wine is racked and the skins are pressed. Most red wine is then matured in oak barrels for a period of time ranging from a few weeks to several years depending on the variety of grapes and the desired wine style before bottling.

The total electrical energy consumed at the manufacturing and filling stage has been estimated as 551 MJ per 1,000 litres of wine. This includes electricity for wine production and bottling the wine. The total water consumption at the manufacturing stage has also been estimated as 1,747 litres per 1,000 litres of wine. The life cycle inventory data for production of electricity and water have been sourced from the Ecoinvent (2010) database.

6.1.2.4 Transport

The modes and distances for transport of grapes, packaging materials, bottled wine and post-consumer waste are summarised in Table 6-3. Transport distances have been estimated based on data from the manufacturer. Due to the lack of specific data, the trucks are assumed to have a total capacity of 40 tonnes. Where no specific data have been available, an average distance of 50 km has been assumed for transport of wine grapes, cork stoppers, kraft paper labels as well as post-consumer waste packaging. The wine is bottled in Australia before shipping to the UK. This is also the general practice for most of the wine consumed in the UK (Garnett, 2007).

Table 6-3 Transport modes and distances

Material	Transport mode	Estimated distance (km)	Source of LCI data
Wine grapes	Truck (40 t)	50	Gabi (PE, 2010)
Wood cork	Truck (40 t)	50	Gabi (PE, 2010)
PP top	Truck (40 t)	50	Gabi (PE, 2010)

Kraft paper	Truck (40 t)	50	Gabi (PE, 2010)
Glass bottle Carton	Truck (40 t) Truck (40 t)	39.2 39.2	Gabi (PE, 2010) Gabi (PE, 2010)
Bottled wine	Truck (40 t) Container ship	128.4 20,031	Gabi (PE, 2010) ILCD (2010), Gabi (PE, 2010)
Post-consumer packaging waste	Truck (40 t)	50	Gabi (PE, 2010)

6.1.2.5 Waste management

As indicated in Table 6-4, the relevant waste streams have been considered, including wastewater treatment of effluents from the winery and disposal of post-consumer waste packaging. The non-recycled fraction of the glass bottle (15%), post-consumer cork and kraft paper labels are sent to landfill at the end of life. The remaining 85% of the glass is sent for recycling but the system is not credited for this to avoid double counting since the recycled content is already assumed in the bottles.

Table 6-4 Waste materials and management options[a]

Waste	Amount (kg/1000 l)	Waste management	Source of data for waste management option
Winery effluents	820	Wastewater treatment	Manufacturer
Glass Carton	93 33	15% landfilled 100% landfilled	British Glass (2009) Assumed
Wood cork PP top	7 1.75	Landfilled Landfilled	Manufacturer Assumed
Kraft paper label	1.4	Landfilled	Manufacturer

[a]All LCI data from the Gabi database (PE, 2010)

6.1.2.6 Data quality

Using the data quality assessment methodology detailed in Chapter 3 of this work, the LCA data quality has been assessed. The overall LCA data quality for the wine system has been estimated as ‘High’. More detail on the data quality assessment is provided in Appendix 2.

6.1.3 Impact assessment and interpretation

The Gabi 4.3 LCA software has been used to model the system. The CML 2001 (Guinee et al., 2001) impacts characterisation method has been used to estimate the environmental impacts. In addition to the impacts considered in the CML method, two further aspects are considered: primary energy demand and water demand. The global warming potential is discussed first followed by the other environmental impacts.

6.1.3.1 Global warming potential (GWP)

The results for the GWP are shown in Figure 6-2 indicating that the total GWP of wine is 1,669 kg CO_2 eq./1,000 l. The raw materials, transport and packaging stages are the major hot spots, contributing 35%, 31% and 24% to the total GWP, respectively. The contribution to GWP from raw materials is mainly due to carbon dioxide emissions from production of pesticides, fertilisers and fuels (diesel and petrol as shown in Figure 6-3.

The contribution to GWP from transport is mainly due to carbon dioxide emissions from production and combustion of fuels from sea and road freight, with the latter two accounting for 84% and 16% of the transport contribution to the GWP, respectively (see Figure 6-4). The contribution from packaging is mainly due to carbon dioxide emissions from manufacturing of glass bottles.

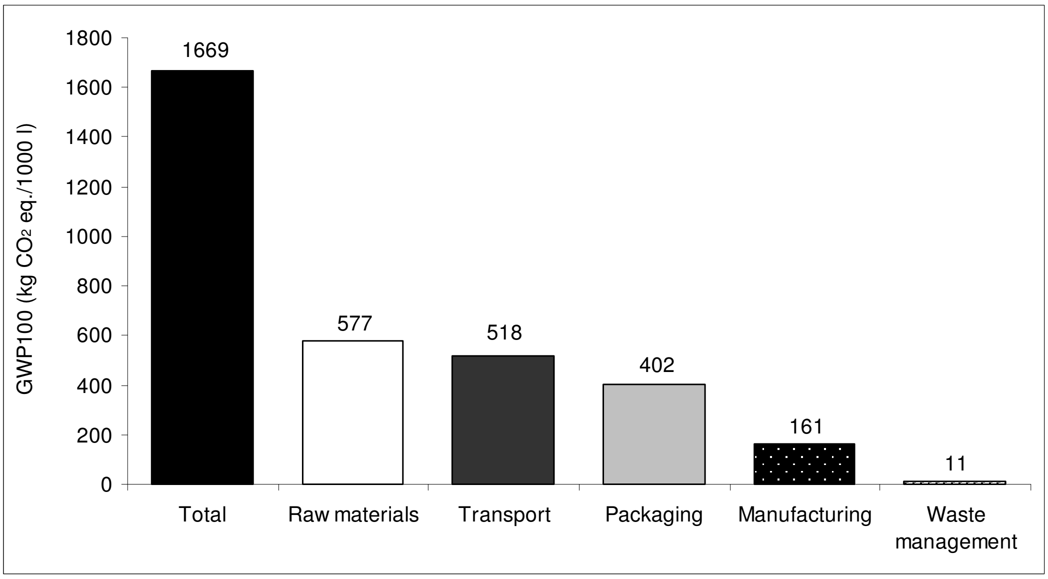

Figure 6-2 Global warming potential of wine also showing the contribution of different life cycle stages

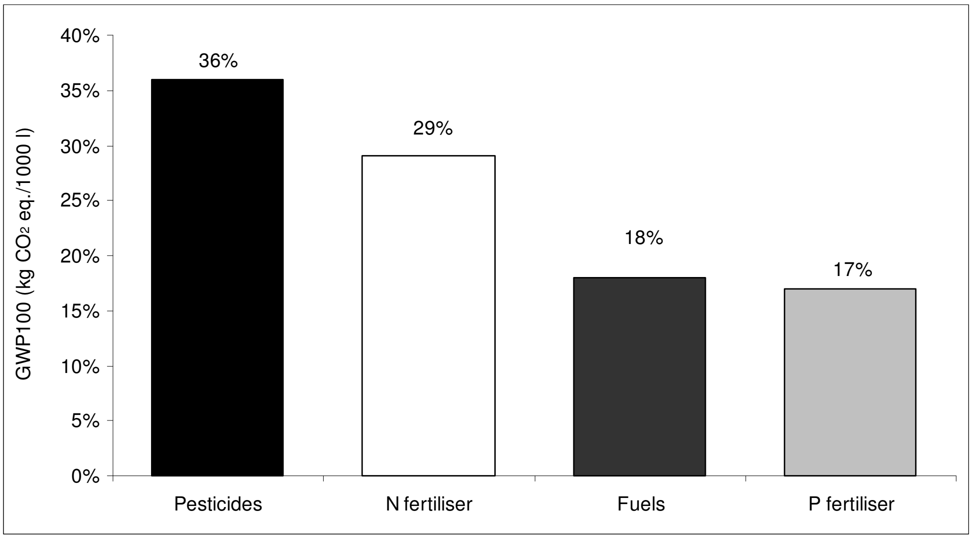

Figure 6-3 Contribution of the raw and auxiliary materials to the global warming potential

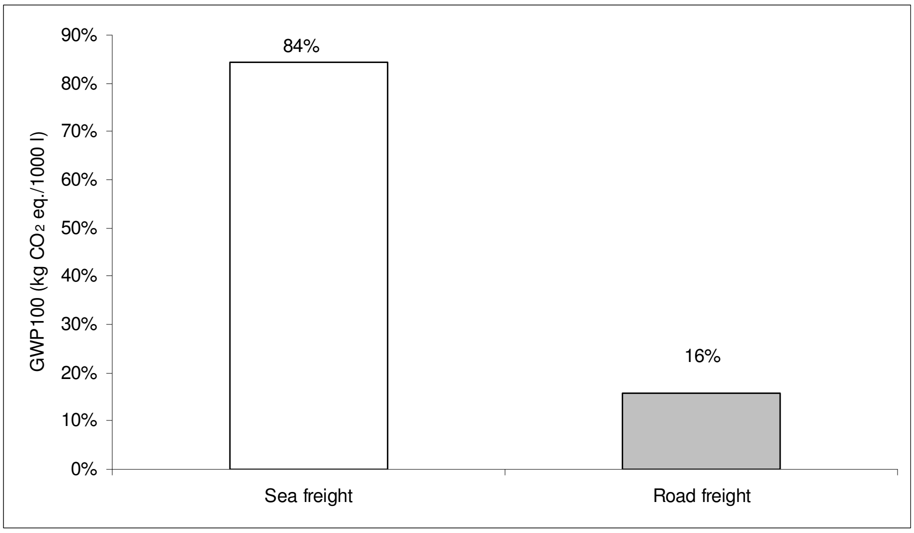

Figure 6-4 Contribution of different transport modes to the global warming potential from transport

6.1.3.2 Impact on GWP of wine shipping

Figure 6-5 indicates that shipping bottled wine from Australia to the UK accounts for 84% of the GWP from transport and 26% of the total GWP. As this is a significant contribution, found not only in this but other studies related to wine shipping (e.g. WRAP, 2007), it is important to consider alternative options. For example, bulk shipping of wine and bottling closer to the consumers has been suggested as one option to mitigate the impact of shipping on GHG emissions in the wine industry. The study by WRAP (2007) estimates that GWP savings of about 218.6 kg CO2 eq. per 1,000 l (164 g per 0.75 l bottle of wine) can be achieved by shipping wine in bulk from Australia to the UK. Applying this estimate to the current study would reduce the total GWP by approximately 13% or to 1,450 kg CO2 eq./1,000 l (Figure 6-6). Other environmental impacts would also be reduced, particularly acidification due to the reduced SOx emissions; however, due to a lack of data, it has not been possible to quantify these savings. Therefore, bulk shipping of wine and bottling closer to the final market should be encouraged to reduce the environmental impacts. In addition to the potential environmental benefits, bulk shipping also results in cost savings through more effective utilisation of container space (WRAP, 2008). On average, 67% more wine (by volume) may be transported by shipping wine in standard flexi-tanks or ISO tanks, compared to standard container shipping[21]. However, issues such as contamination (from residues of previous cargoes) and negative consumer perceptions may hinder the widespread adoption of bulk shipping of wine.

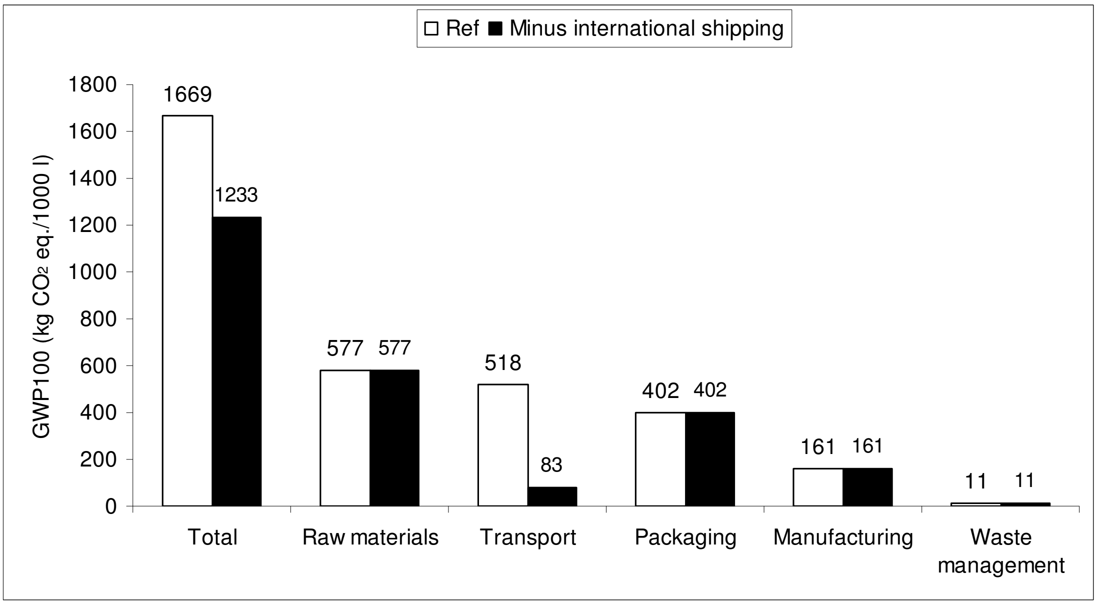

Figure 6-5 Impact of international shipping on the global warming potential
[Ref – reference case as considered in the study, including shipping]

[21] A standard container holds 12,000 to 13,000 bottles, whilst standard flexi-tanks and ISO hold the equivalent of approximately 32,000 and 35,000 bottles, respectively (WRAP, 2008).

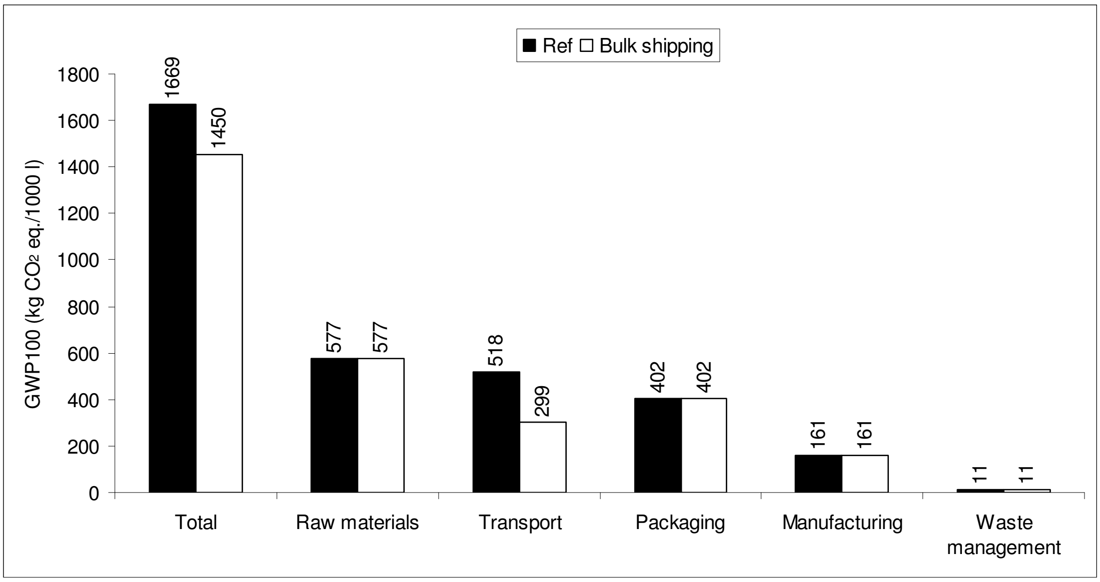

Figure 6-6 Impact of bulk shipping on the global warming potential
[Ref – reference case as considered in the study, including shipping]

6.1.3.3 Comparison of GWP results with other studies

The results for the GWP have been compared with other studies as shown in Figure 6-7 to Figure 6-9. The results shown in Figure 6-7 (cradle to gate) exclude delivery of the final product to the consumer and waste management systems for post-consumer waste. This is due to a high variability in transportation means and distances, as well as differences of local waste management regulations. Figure 6-8 and Figure 6-9 focus on emissions from the grape growing and wine making stages, respectively. Overall, there is a relatively good agreement between this and other studies, given the differences in specific processes that have been included and excluded from the analyses, varying agricultural practices and the fact that the wine is produced in different geographical regions such as USA, Europe and Australia. The latter is a crucial factor as different geographical regions have unique soil types and climate, operate at different production scales, and have different levels of efficiency as well as energy mixes (Garnett, 2007).

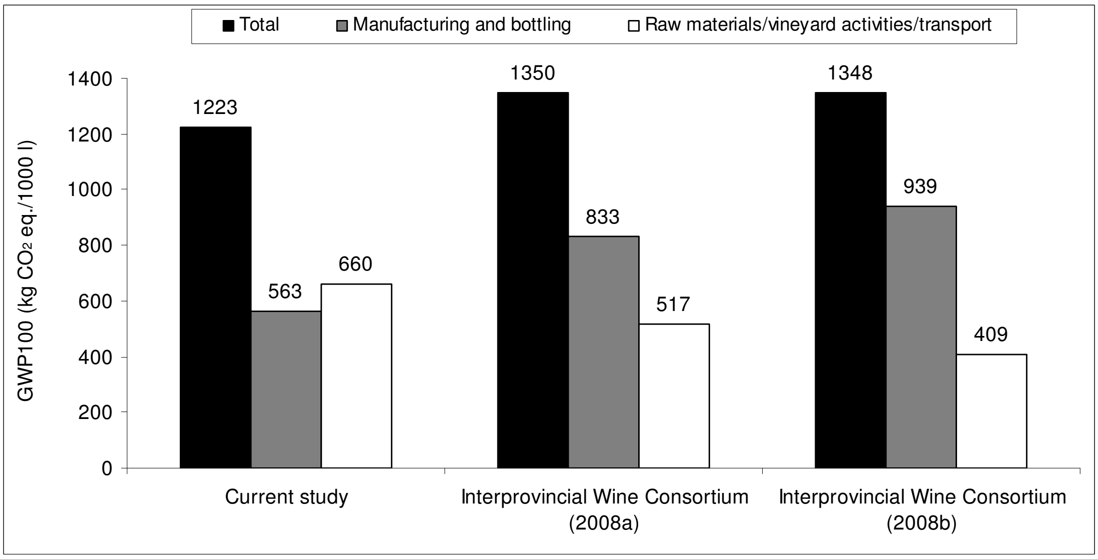

Figure 6-7 Comparison of global warming potential with other studies (cradle to gate)

[The studies with which the current study is compared are based on production of sparkling wine, which may explain their higher impact]

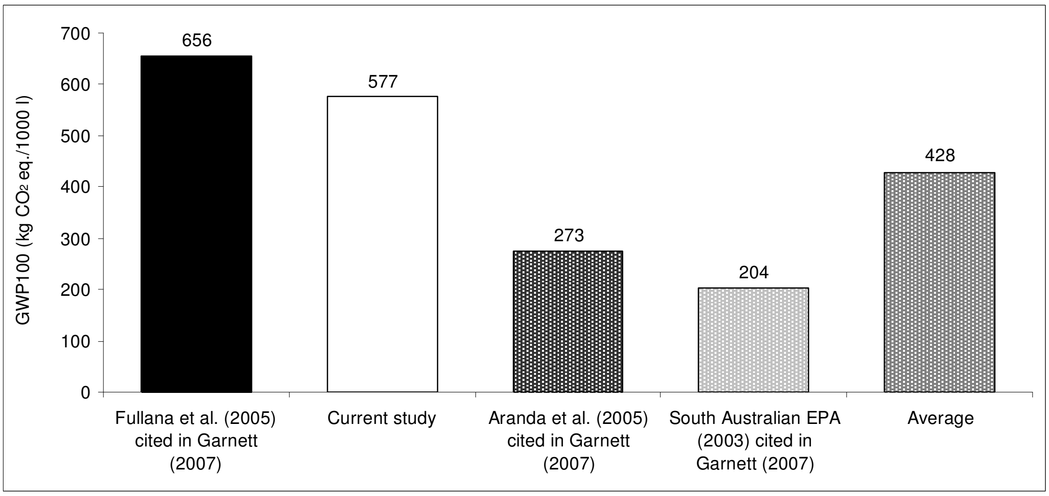

Figure 6-8 Comparison of global warming potential from grape growing with other studies

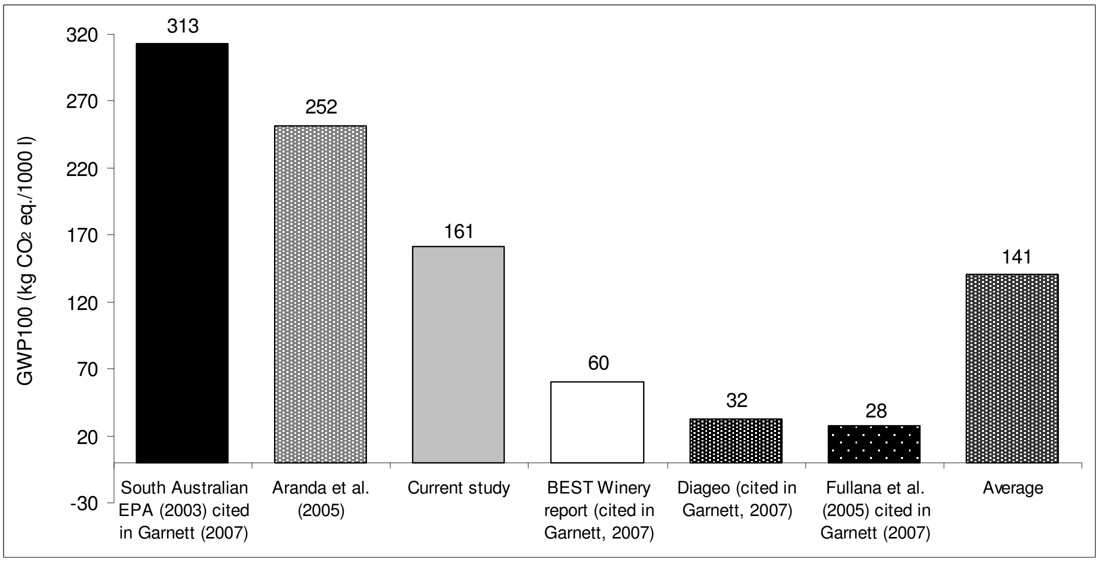

Figure 6-9 Comparison of global warming potential from manufacturing with other studies

6.1.3.4 Other environmental impacts

The environmental impacts (other than GWP) in the life cycle of wine are shown in Figure 6-10. The contributions to these impacts of different life cycle stages are shown in Figure 6-11. Similar to the GWP, raw materials, transport and packaging are the major contributors to the impacts. Production of raw materials is the major contributor to 7 out of 11 impact categories: primary energy demand (PED), water demand (WD), abiotic depletion (ADP), human toxicity (HTP), marine, freshwater and terrestrial ecotoxicity (MAETP, FAETP, TETP) potentials. Emissions arising from the production and use of pesticides, fertilisers and fuels are mainly responsible for impacts from the raw materials stage. Consumption of water for cultivation of wine grapes is mainly responsible for WD.

Transport is the key life cycle stage regarding acidification (AP), eutrophication (EP), ozone depletion (ODP) and photochemical oxidant creation (POCP) potentials, mainly due to atmospheric emissions of sulphur dioxide and nitrogen oxides from sea freight. Manufacturing is also a key life cycle stage regarding EP, accounting for 30% of the total. Emissions of organic compounds to freshwater arising from the winery effluents are mainly responsible for the manufacturing contribution to EP.

Packaging is also an important contributor to PED, AD, HTP, MAETP, FAETP and ODP, accounting for over 20% of the total in each impact category. Emissions of the heavy metal selenium, an important burden for human toxicity, arise mainly from production of glass bottles. Packaging is also the key contributor to atmospheric hydrogen fluoride emissions, mainly responsible for MAETP. Manufacture of packaging also contributes to emissions Non-Methane Organic Volatile Compounds (NMVOC) which are mainly responsible for ODP.

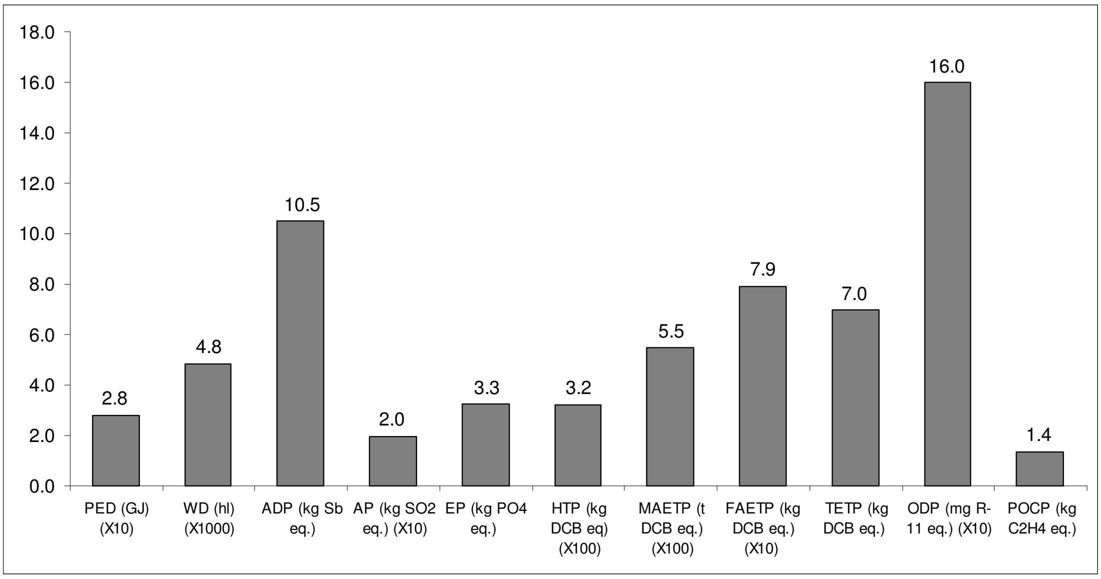

Figure 6-10 Environmental impacts (other than GWP) in the life cycle of wine
[*PED* primary energy demand, *WD* water demand, *ADP* abiotic depletion potential, *AP* acidification potential, *EP* eutrophication potential, *HTP* human toxicity potential, *MAETP* marine aquatic ecotoxicity potential, *FAETP* freshwater aquatic ecotoxicity potential, *TETP* terrestrial ecotoxicity potential, *ODP* ozone depletion potential, *POCP* photochemical ozone creation potential. The scaled values should be multiplied with the factor shown in brackets against the relevant impact to obtain the original values.]

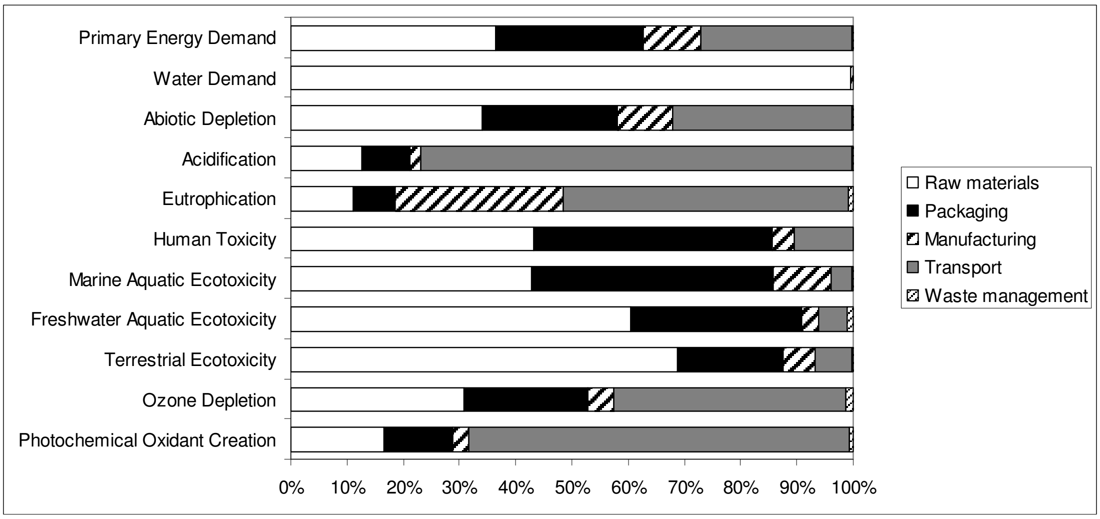

Figure 6-11 Contribution of different life cycle stages to environmental impacts

The life cycle impacts for the GWP as well as other environmental categories have been compared with other studies from cradle to grave as shown in Figure 6-12. However, the impacts from the use stage and production of secondary packaging have been subtracted from the other studies in order to compare the systems on an equivalent basis. Overall the results show relatively good agreement (except EP) considering differences in geographical regions, different waste management scenarios, bottle weights and recycled content, as well as distribution scenarios. Furthermore, similar to the current study, cultivation of wine grapes and production of glass bottles are shown to be important contributors to the environmental impacts.

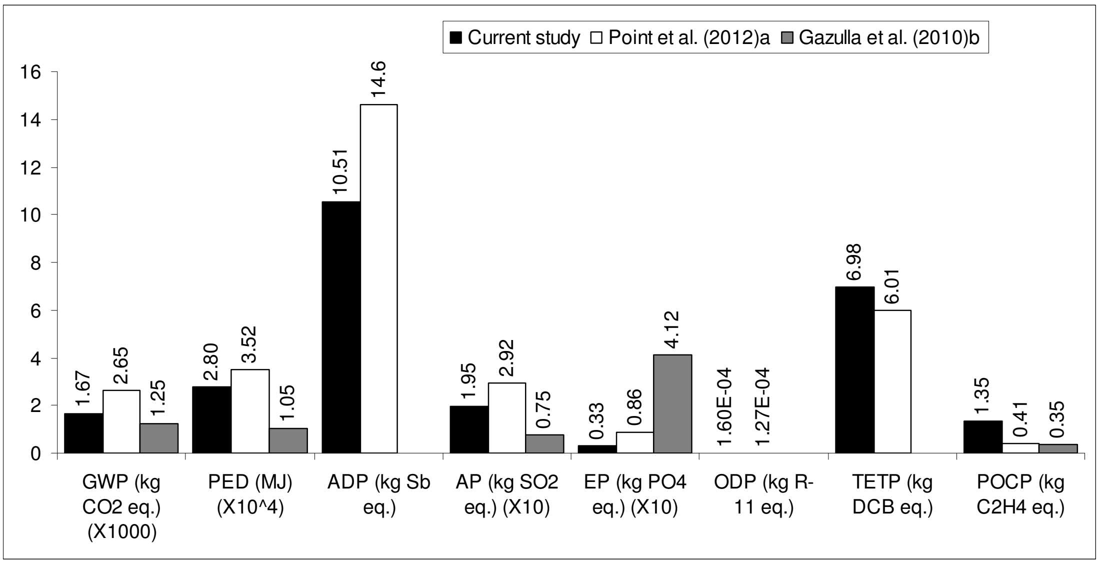

Figure 6-12 Comparison of other impacts (including GWP) with other studies
[The scaled values should be multiplied with the factor shown in brackets against the relevant impact to obtain the original values. [a]Life cycle impacts of wine produced and consumed in Canada; minus impacts from the use stage and secondary packaging (cardboard production). [b]Life cycle impacts of wine produced and consumed in Spain; minus impacts from secondary packaging (barrel production)]

6.1.3.5 Environmental impacts at the sectoral level

In order to determine the life cycle environmental impacts from the UK wine sector, the results of the current study have been extrapolated for the total consumption of Australian wines in the UK for the year ending March 2011. The total volume of non-sparkling wine under 15% alcohol by volume (ABV) available for consumption in the UK for the specified period amounted to 12 million hectolitres, of which the 'take-home' market accounted for 8 million hl. Furthermore, recent estimates show that imports from Australia accounted for 17.4% of the UK wine market (Key Note, 2011) therefore, the total volume of Australian wines in the UK market amounted to 1.4 million hl for the year ending March 2011.

From Figure 6-13, it can be see that consumption of Australian wines in the UK was responsible for around 232,000 tonnes CO_2 eq. for the year ending March 2011. This represents about 2.3% of the GHG emissions from the whole food and drink sector[22].

[22] Estimated based on the stated contribution by FDF (2008) and Defra (2006) of the food and drink sector of 2% to total UK GHG emissions.

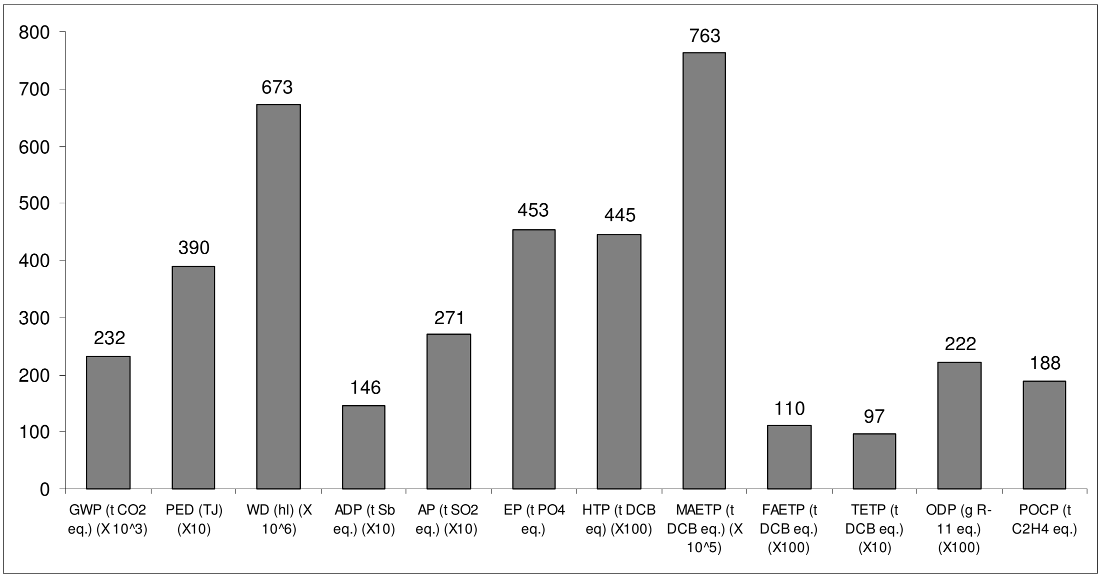

Figure 6-13 Life cycle environmental impacts of wine in the UK[23]
[The scaled values should be multiplied with the factor shown in brackets against the relevant impact to obtain the original values.]

7.1.3.6 Impact of recycled glass content on the environmental impacts

Given that packaging is a hot spot for the environmental impacts in the life cycle of wine, the impact of the recycled content of the glass bottles on the environmental impacts has been assessed. The results are shown in Figure 6-14 to Figure 6-16. 0% recycled content represents glass bottles manufactured from virgin glass, while 100% recycled content represents glass bottles manufactured entirely from recycled glass cullet. The reference scenario shown represents bottles containing 85% recycled content. The results in Figure 6-14 show that by increasing the amount of recycled glass by 10%, the GWP would be reduced by about 2% of 29 kg CO_2 eq. per functional unit. The savings in GWP arise from the packaging and waste management stages due to reduced energy consumption for manufacturing of bottles and reduced post-consumer waste sent to landfill. Environmental impact savings for the other environmental impacts range from 0.7% (POCP) to 1.2% (HTP). Although the savings in the environmental impacts appear minimal, they are nevertheless significant at the sectoral level as shown in Figure 6-16. For example, 2% savings in the GWP amounts to over 4,000 tonnes of GHG emissions. Thus, there is a clear case for increasing the recycled content of glass packaging.

[23] The environmental impacts are estimated for Australian wines in the UK market.

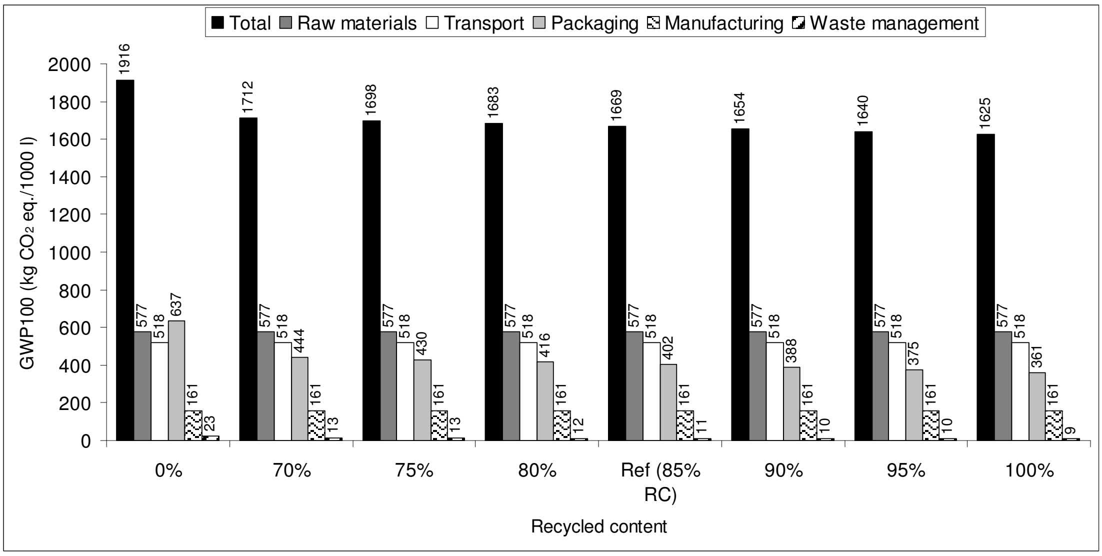

Figure 6-14 Impact of recycled content on the global warming potential per 1000 litres of wine

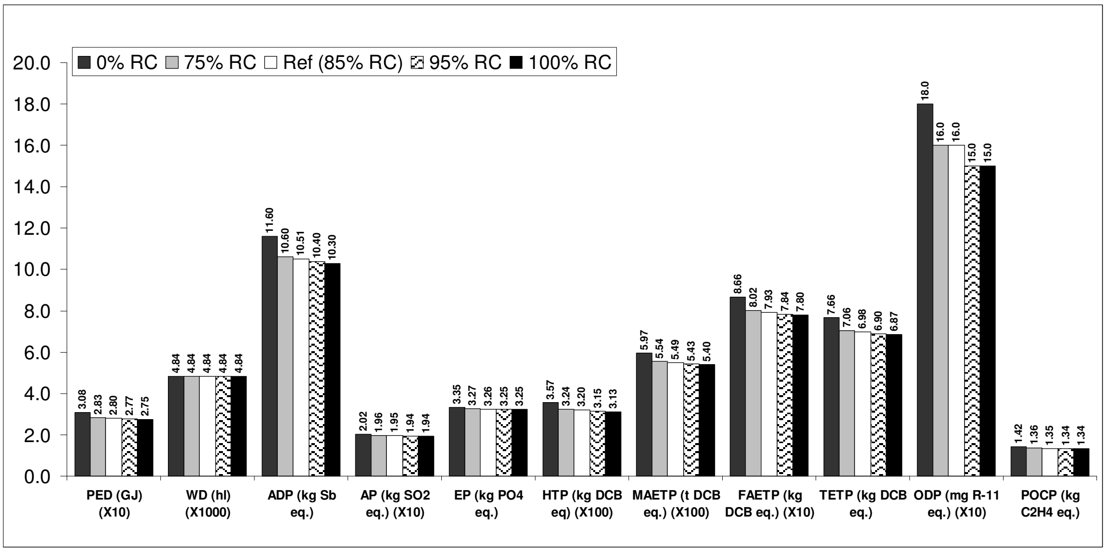

Figure 6-15 Impact of recycled content on the environmental impacts per 1000 litres of wine

[The scaled values should be multiplied with the factor shown in brackets against the relevant impact to obtain the original values.]

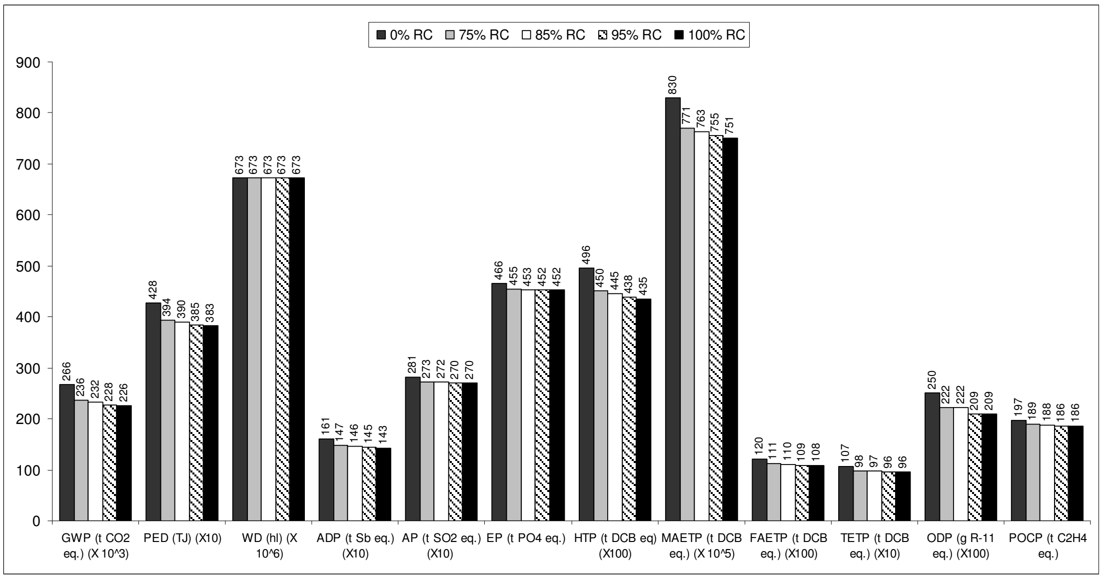

Figure 6-16 Impact of recycled content on the environmental impacts at the sectoral level

[The scaled values should be multiplied with the factor shown in brackets against the relevant impact to obtain the original values.]

6.1.3.7 Impact of lightweighting on the environmental impacts

Figure 6-17 to Figure 6-19 show the effect of lightweighting on the environmental impacts in the life cycle of wine. The results in Figure 6-17 show that reducing the weight of glass bottles by 10% results in GWP savings of about 4% or 57 kg CO_2 eq. per 1,000 l of wine. The savings arise from reduced energy and material for manufacturing of glass bottles and reduced impacts from transporting less glass. Environmental impact savings in other categories range from 2.7% (TETP) to 6.9% (ODP) as shown in Figure 6-18. This is even more significant at the sectoral level where a 10% reduction in the weight of glass bottles results in GWP savings of about 9,620 tonnes per year. These results help to establish lightweighting as an important option for reducing the environmental impacts in the wine sector.

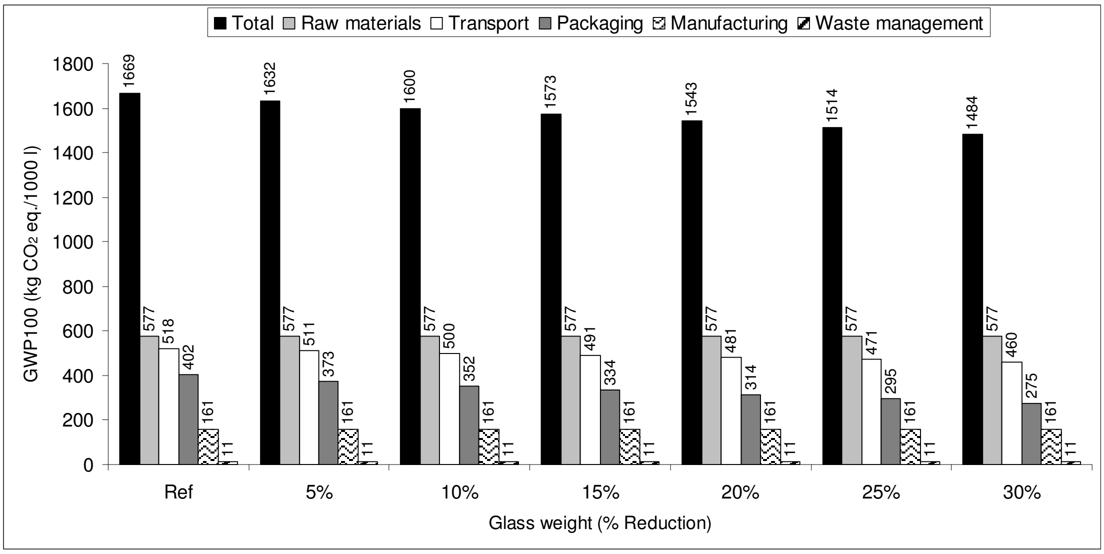

Figure 6-17 Impact of lightweighting on the global warming potential per 1000 litres of wine

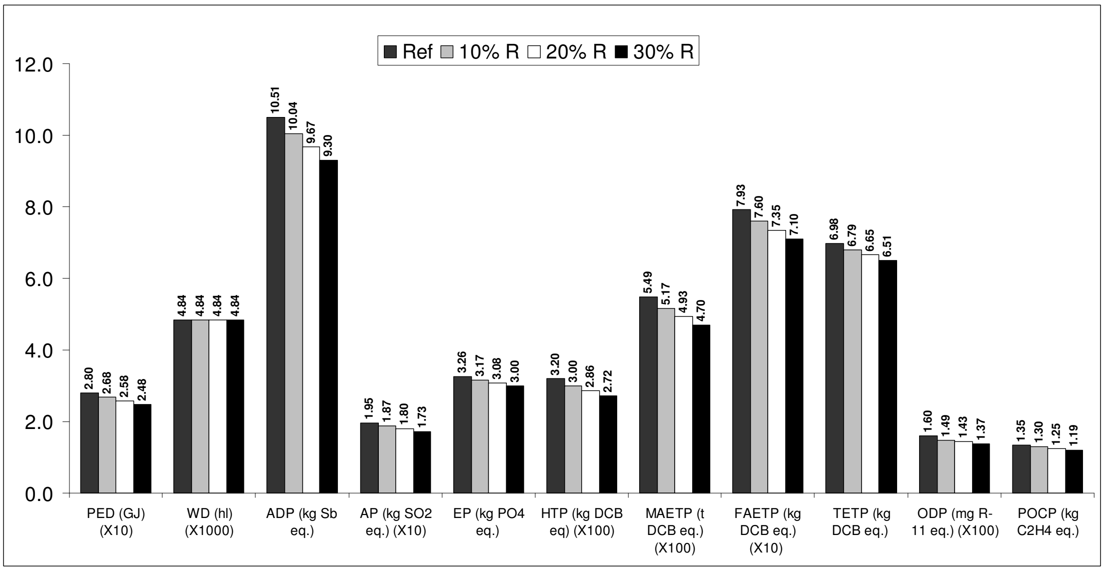

Figure 6-18 Impact of lightweighting on the environmental impacts per 1000 litres of wine

[R- reduction. The scaled values should be multiplied with the factor shown in brackets against the relevant impact to obtain the original values.]

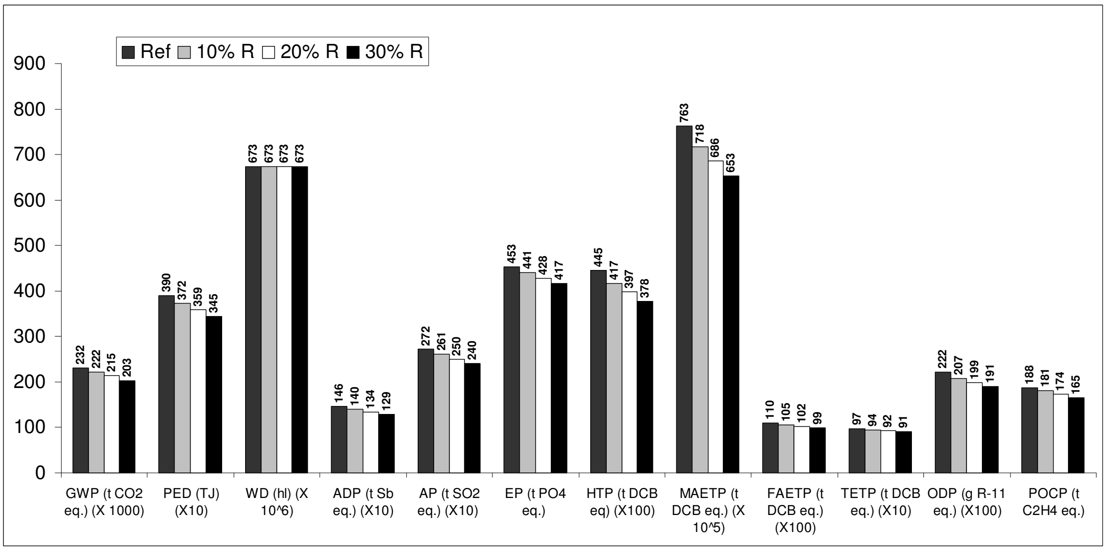

Figure 6-19 Impact of lightweighting on the environmental impacts at the sectoral level

[R- reduction. The scaled values should be multiplied with the factor shown in brackets against the relevant impact to obtain the original values.]

6.1.3.8 Impact of carton packaging on the environmental impacts

In addition to increasing the recycled content and lightweighting of glass bottles, the effect of using cartons for packaging of wine has been assessed as part of the improvement options in this work. It has not been possible to ascertain the volume of wines packaged in cartons in the UK market due to lack of data. However, recent reports show that a number of wine producers and importers are set to introduce wines packaged in cartons into the UK market (FDIN, 2012) Furthermore, the Food and Drink Innovation Network (FDIN) report that around 10% of still wines in the global market are packaged in cartons (FDIN, 2012). As can be seen in Figure 6-20, packaging wine in cartons results in savings in all the environmental categories considered except WD, where the impact is similar to the glass bottle system. For example, compared to the current operations, packaging wine in cartons reduces the GWP by around 51% compared to the glass bottles. The GWP savings arise mainly from reduction in the energy required for manufacturing the packaging and reduced transport emissions from transporting significantly lighter cargo. In other environmental impact categories, the savings range from 25% (EP) to 70% (MAETP).

At the sectoral level, introduction of this packaging format can contribute to significant environmental savings as shown in Figure 6-21. The results in Figure 6-21 are based on a hypothetical model which assumes a 10% penetration of cartons in the UK market for Australian wines compared to the reference case (100% glass bottles) as considered in the current study. It can be seen from Figure 6-21 that a 10% penetration of cartons in the market results in GWP savings of around 5% (11,700 tonnes CO_2 eq.). Savings in other environmental impact categories range from 2% (EP) to 10% (PED).

These results show that there is a compelling case for the widespread adoption of cartons in the wine industry. However, other factors such as economic aspects, consumer perception, ease of transportation, shelf life and potential impacts on the glass bottle industry (e.g. in the area of jobs) need to be investigated to facilitate more informed decision making in this area.

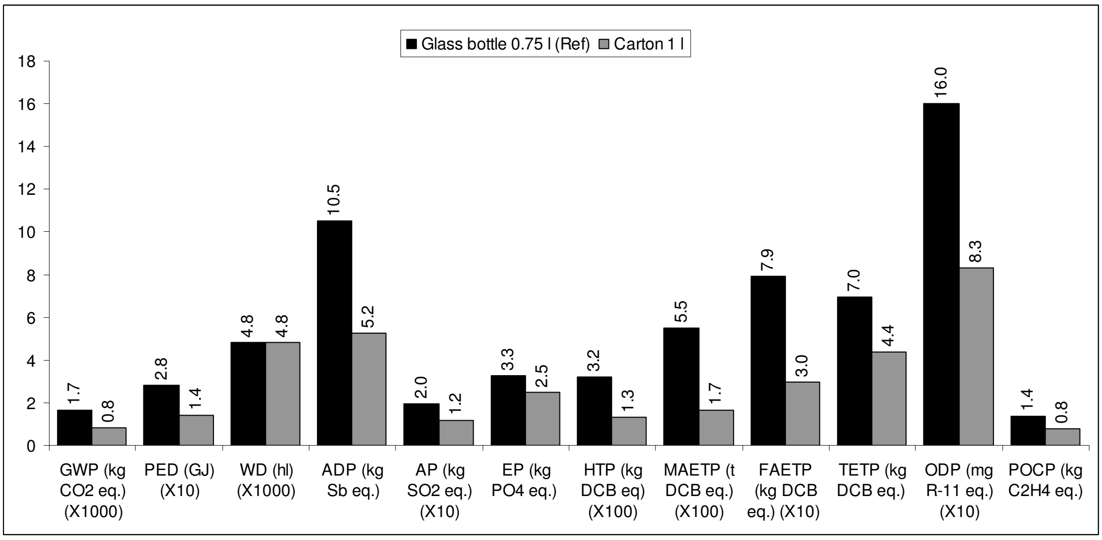

Figure 6-20 Impact of carton packaging on the environmental impacts per 1000 litres of wine

[Ref – reference case as considered in the study. The scaled values should be multiplied with the factor shown in brackets against the relevant impact to obtain the original values.]

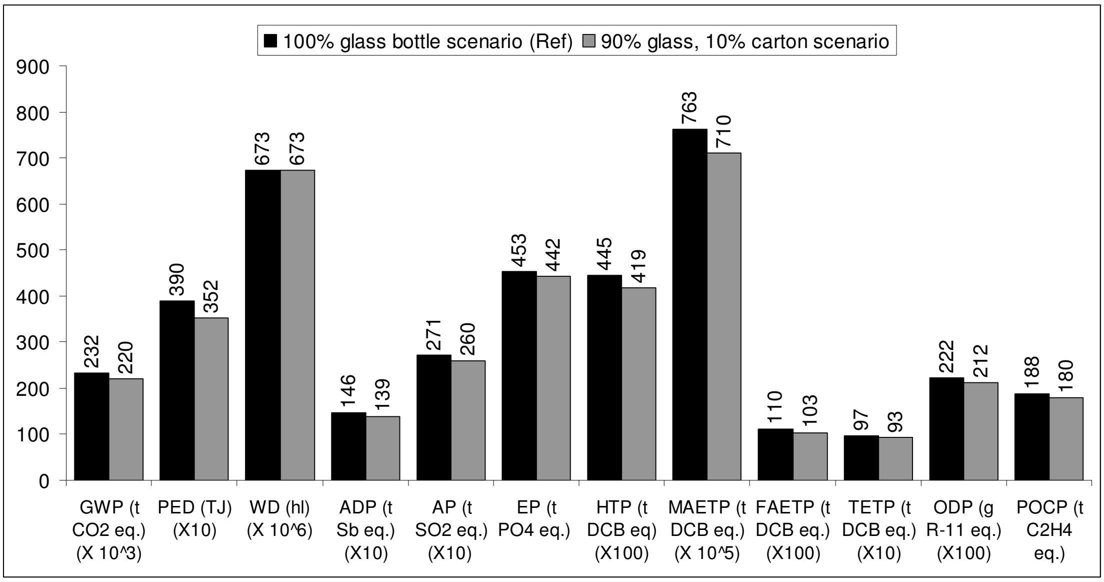

Figure 6-21 Impact of carton packaging on the environmental impacts at the sectoral level

[Ref – reference case as considered in the study. The scaled values should be multiplied with the factor shown in brackets against the relevant impact to obtain the original values.]

6.1.3.9 Impact of organic viticulture on the environmental impacts

Given that the raw materials stage is a major contributor to the environmental impacts, mainly due to production of pesticides, fertilisers and fuels, the effect of organic grape production on the environmental impacts has been assessed. The study by Point et al. (2012) estimates that environmental savings ranging from 30% (TETP) to 1% (Energy demand, ADP, ODP) can be achieved by producing wine grapes based on organic viticulture[24]. However, the study also estimates that organic viticulture may lead to increased AP and EP by around 3% and 2%, respectively. Figure 6-22 and Figure 6-23 show the impact of organic viticulture on the life cycle environmental impacts based on the estimates by Point et al. (2012). From Figure 6-22 it can be seen that organic viticulture does not lead to a change in the GWP, while marginal savings are achieved with regard to PED, ODP and POCP. The most significant impact reduction (30%) is seen in the TETP category, while marginal increases are observed with regard to AP and EP. While the savings and increases may appear marginal when considered per unit of product, they are more significant at the sectoral level. For example, AP and EP would increase by 80 tonnes SO_2 eq. and 8 tonnes PO_4 eq.,

[24] Based on a hypothetical model of grape cultivation in Canada which substituted conventional fertilisers and pesticides with organic substitutes as defined by the Canadian General Standards Board Organic Production Systems Permitted Substance List (Point et al., 2012).

respectively. 30% reduction in the TETP, on the other hand, amounts to savings of around 290 tonnes DCB eq. annually (Figure 6-23).

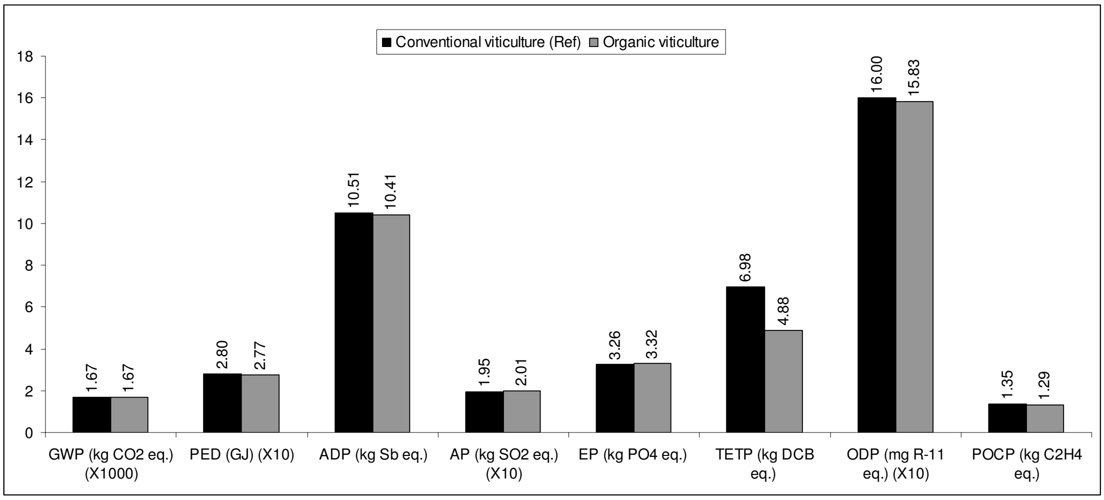

Figure 6-22 Impact of organic viticulture on the environmental impacts per 1000 litres of wine

[Ref – reference case as considered in the study. The scaled values should be multiplied with the factor shown in brackets against the relevant impact to obtain the original values.]

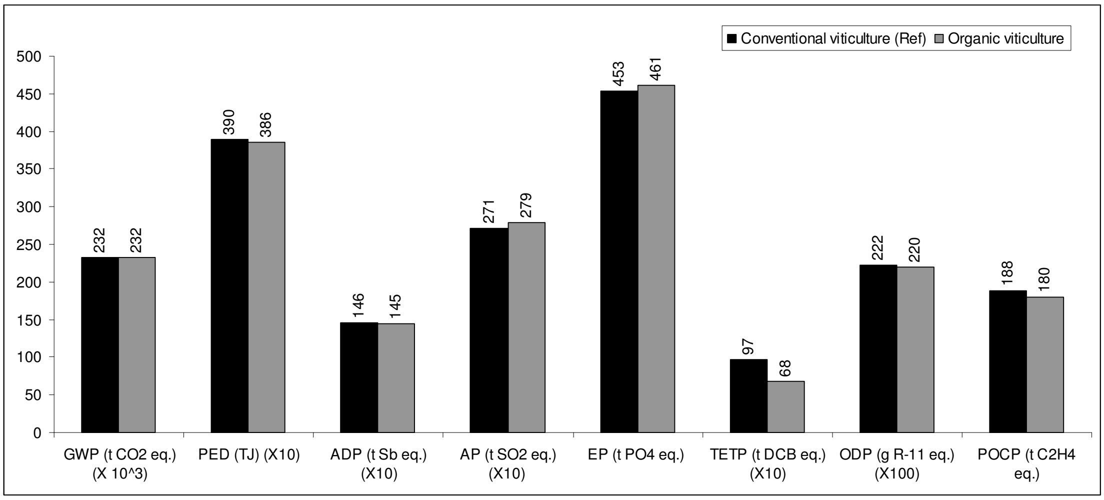

Figure 6-23 Impact of organic viticulture on the environmental impacts at the sectoral level

[Ref – reference case as considered in the study. The scaled values should be multiplied with the factor shown in brackets against the relevant impact to obtain the original values.]

6.2 Life cycle economic assessment

Two economic aspects are considered in this study: life cycle costs and value added. The methodology follows that used by the LCA as far as possible; further details on the LCC and VA methodologies can be found in Chapter 3. The life cycle costs are considered from the perspective of the beverage manufacturer, consumer and the government.

6.2.1 Goal and scope of the LCC

The LCC has three main goals:

i. to estimate the life cycle costs and value added and identify the hot spots in the life cycle of wine produced in Australia and consumed in the UK;
ii. to estimate the life cycle costs and value added for the wine sub-sector based on the findings from the first goal of the case study and a UK market analysis; and
iii. to estimate the impact of improvement options on the life cycle costs and value added.

Similar to the LCA, the functional unit is based on 1,000 litres of wine while the sectoral analysis considers total annual production of Australian wines and consumption in the UK.

6.2.2 Inventory data and assumptions

The life cycle inventory data are based on the LCA data presented in section 6.1.2. Primary production cost data have been obtained from literature, including the costs of raw materials for cultivation of wine grapes, the costs of electricity, fuels and auxiliary materials for manufacturing of wine. It is assumed that freight costs are included in the costs of materials; therefore the cost impact for each material in the life cycle includes transport. It is also assumed that the manufacturer bears the costs of raw materials, electricity and auxiliary materials for manufacturing, as well as waste management of in-process waste. The consumer, on the other hand, bears the costs for disposal of post-consumer waste packaging through taxes paid for waste disposal services. More detail on the cost data are provided below.

6.2.2.1 Raw materials

The sources for the costs of raw materials for cultivation and harvest of wine grapes are summarised in Table 6-5. It is important to note that the costs of fertilisers and fuels are based on prices available in the global commodity market and are not specific to Australia due to lack of data.

Table 6-5 Raw material costs for cultivation and harvest of wine grapes

Raw material	Cost (£/1000 l)	Source of cost data
Water	675.7	Australian Bureau of Statistics (2011)
Nitrogen fertiliser	3.5	Indexmundi.com (2011)
Phosphorus fertiliser	4.8	Indexmundi.com (2011)
Diesel	3.9	Indexmundi.com (2011)
Petrol	1.5	Indexmundi.com (2011)

6.2.2.2 Packaging

The costs of packaging materials are summarised in Table 6-6. It is important to note that the material costs shown do not include the costs associated with fabrication of the specific type of packaging (bottles, corks and labels). This is a limitation of the study but due to the lack of data (confidentiality), it was not possible to obtain these data.

Table 6-6 Costs of packaging materials in the life cycle of wine

Packaging type	Cost (£/1000 l)	Source of cost data
Primary glass (15% content)[a] Recycled glass cullet (85% recycled content)[b]	79.1 4.0	Ali express (2011) WRAP (2011)
Cork stoppers[c]	2.4	Ali express (2011)
Kraft paper labels[d]	0.5	FOEX indexes (2011)

[a] Market price of green container glass per kg.
[b] Average price per kg of recycled glass cullet.
[c] Represents the seller price of fabricated cork stoppers.
[d] Market price of kraft paper in the global commodity market.

6.2.2.3 Manufacturing

The costs for electricity and other auxiliary materials are summarised in Table 6-7. With the exception of utilities (water and electricity), the cost data for the manufacturing inputs are not specific to Australia, due to lack of data.

Table 6-7 Costs of energy and materials for wine manufacturing

Energy/material	Cost (£/1000 l)	Source of cost data
Process water	2.4	Australian Bureau of Statistics (2011)
Sodium hydroxide	0.7	ICIS (2010)
Natural gas	9.3	DECC (2010)
Diesel	0.5	Indexmundi.com (2011)
Petrol	2.9	Indexmundi.com (2011)
Electricity	29.1	Western Australia Office of Energy (2011)
Effluents from winery	1.6	Scottish Water (2011)

6.2.2.4 Waste management (post-consumer)

The waste disposal costs for post-consumer waste packaging are summarised in Table 6-8. It is assumed that the non-recycled fraction (15%) of the glass bottle as well as the cork stoppers and kraft paper labels are sent to landfill at the end of life.

Table 6-8 Costs of packaging waste management [a]

Waste	Cost (£/1000 l)
Glass bottles (15% to landfill)	11.7
Cork stoppers	0.5
Kraft paper labels	0.1

[a]All cost data from WRAP (2011)

6.2.2.5 Consumer costs

As observed earlier in section 6.2.2, it has been assumed that the consumer bears the costs of disposal of post-consumer packaging waste through taxes paid for waste disposal services. These are shown as landfill costs in Table 6-8. The retail price of the product, which has been used to estimate VA, can also be classified as consumer costs.

6.2.3 Life cycle economic impacts and interpretation

The LCC is discussed first followed by the results of the VA analysis. Following this, the two economic aspects are discussed for the wine sub-sector after which the impacts of improvement options on the economic performance are discussed.

6.2.3.1 Life cycle costing (LCC)

The results of the LCC are given in Figure 6-24. The LCC results shown represent the life cycle costs accrued by the manufacturer, excluding the costs for disposal of post-consumer waste packaging which are borne by the consumer. However, post-consumer waste disposal costs are negligible, accounting for 1% of the total LCC. As can be seen, the LCC has been estimated as £791 per 1,000 l or 60 pence per bottle. This is 3.6 times higher than the LCC of beer £217 per 1,000 l (see the previous chapter), which is also produced from an agricultural crop and has a similar manufacturing process. This is mainly due to the water required for production of wine grapes which is around 57 times higher than that required for barley production. The production of raw materials is the major hot spot contributing 87% to the total LCC. This is mainly (98%) due to water for cultivation of wine grapes. Packaging and manufacturing, on the other hand, account for only 7% and 6%, respectively of the LCC. As previously observed in section 6.2.2, transport costs are included in the costs of materials therefore, transport has not been considered as a separate life cycle stage in the LCC analysis.

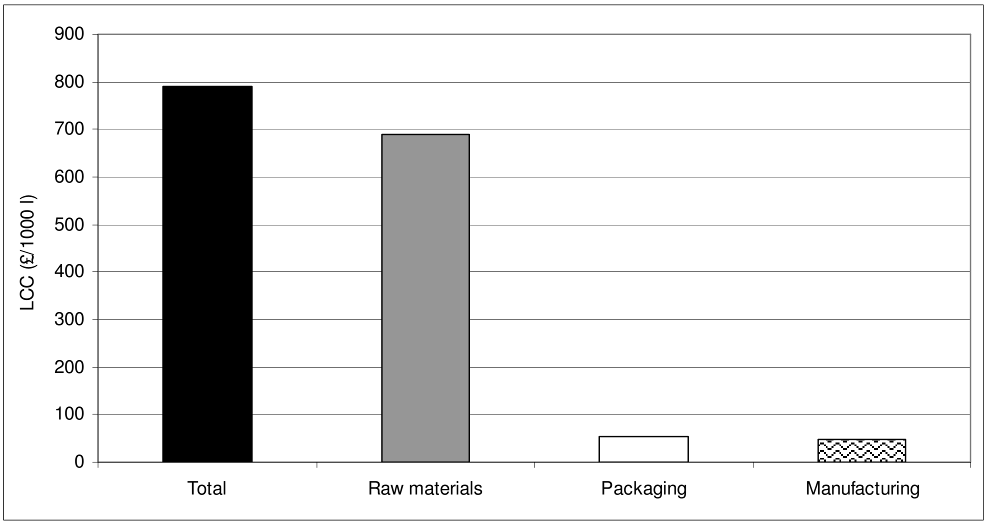

Figure 6-24 Life cycle costs of wine also showing the contribution of different life cycle stages

6.2.3.2 Value added (VA)

The VA, calculated as the difference between the retail price and the LCC, is estimated at £10,662 per 1,000 l. Similar to the LCC, the VA of wine is around 3.6 times higher than that of beer packaged in glass bottles due to its significantly higher retail price (£10,728/1,000 l compared to £3,238/1,000 l). The retail price has been estimated based on the average price of medium-range South Australian wine in the UK[25] of £8.59 per bottle.

6.2.3.3 Life cycle costs and value added at the sectoral level

Similar to the LCA, the economic impacts of Australian wines in the UK market have been estimated by extrapolating the LCC and VA results for the total consumption of 1.4 million hl for the year ending March 2011. From Figure 6-25, it can be seen that consumption of Australian wines in the UK was responsible for over £100 million in life cycle costs for the year ending March 2011. The VA for the reference year is estimated to be about £1.5 billion, amounting to around 0.1% of the UK GDP[26].

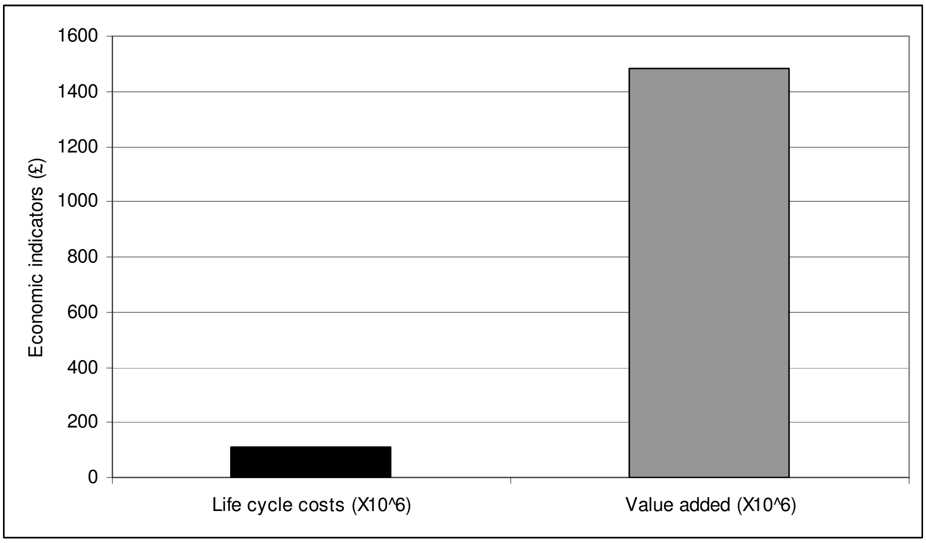

Figure 6-25 Annual LCC and VA from consumption of Australian wines in the UK

6.2.3.4 Impact of recycled content on the economic impacts

As part of the sensitivity analysis, the effect on the economic impacts of increasing the recycled content of the glass bottles has been assessed. The results shown in Figure 6-26 suggest that increasing the recycled content by 10% results in LCC savings of around 4% and increase in VA of around 0.3%. At the sectoral level, this

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[25] Based on the average prices of four medium range South Australian Red wines (Hardy's, McGuigan, McWilliams Hanwood and Howcroft) available in the major UK retail outlets: Asda, Tesco, Sainsburys and Waitrose; accessed 25 July 2011.

[26] Based on the stated UK GDP of £1,392,634 million for 2009 (Key Note, 2011); sourced from Economic and Labour Market Review, November 2010, National Statistics website.

amounts to savings in production costs and increased revenue of around £4.3 million[27].

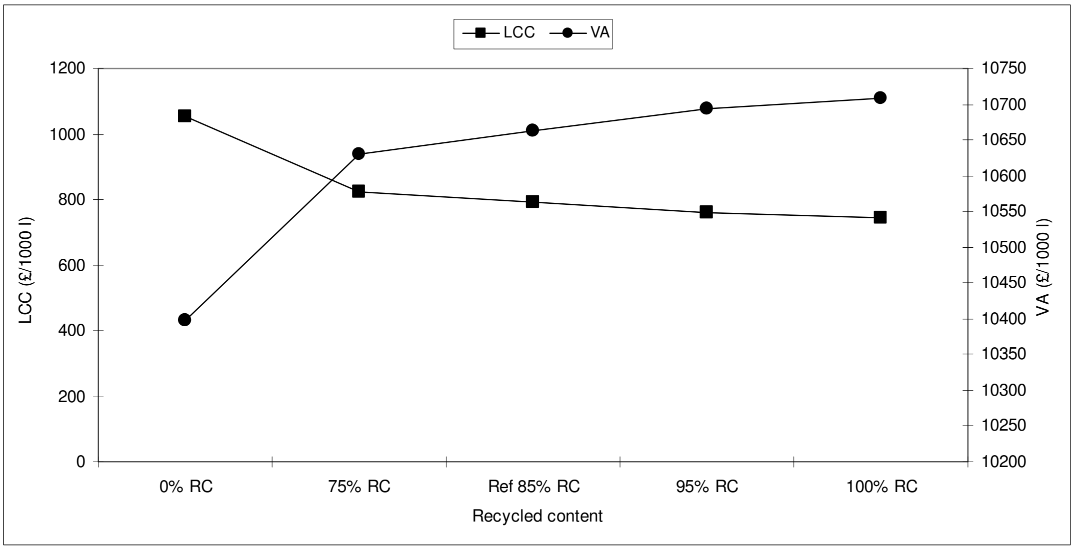

Figure 6-26 Impact of recycled content on life cycle costs and value added

6.2.3.5 Impact of lightweighting on the economic impacts

The impact of lightweighting of glass bottles on the economic impacts has also been assessed as part of the sensitivity analysis. The results in Figure 6-27 suggest that 10% reduction in the bottle weight would reduce the LCC by around 0.6% and increase VA by around 0.1%. At the sectoral level, this amounts to savings in production costs and increased revenue of around £700,000 which is around 6 times less than the savings that can be achieved by increasing the recycled content. Nevertheless, these results demonstrate that increasing the recycled content and lightweighting result in environmental and economic savings.

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[27] Based on the estimated consumption of ~ 139 million litres of Australian wine in the UK for the year ending March 2011.

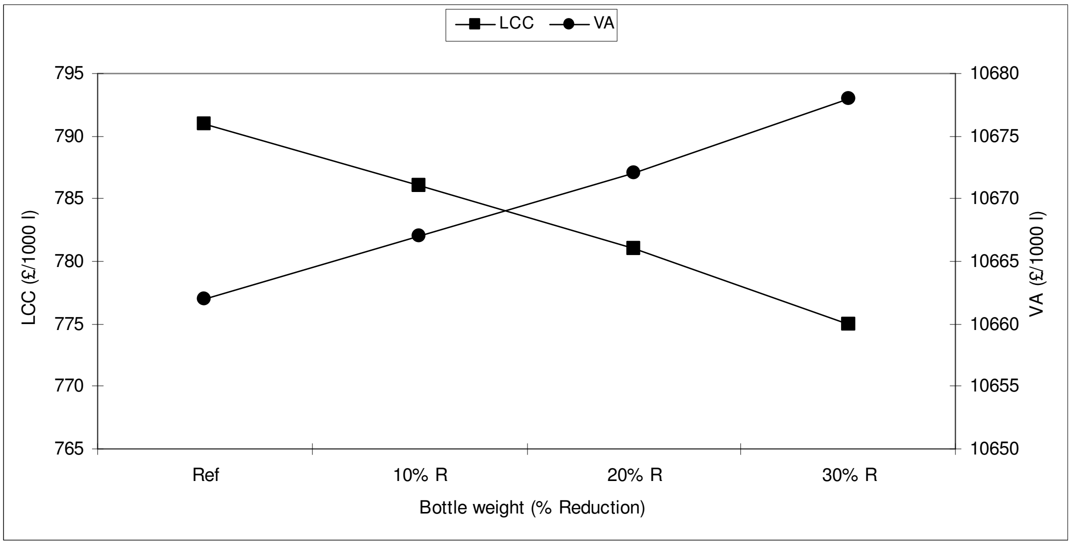

Figure 6-27 Impact of lightweighting on life cycle costs and value added

6.3 Comparison of environmental and economic sustainability

Following the methodology detailed in Chapter 3 of this work, Figure 6-28 shows the contribution of different life cycle stages to the environmental and economic impacts. This enables the identification and comparison of the environmental and economic hot spots in the life cycle of wine. It can be seen that production of raw materials, transport and packaging are the key hot spots for the environmental impacts, while the raw materials stage is the major contributor to the LCC. Furthermore, Figure 6-29 to Figure 6-30 show the impact of recycled content and lightweighting on the GWP and LCC in the life cycle of wine. As can be seen in Figure 6-29 and Figure 6-30, increasing the recycled content and lightweighting of glass bottles result in both environmental and economic improvements in the life cycle of wine.

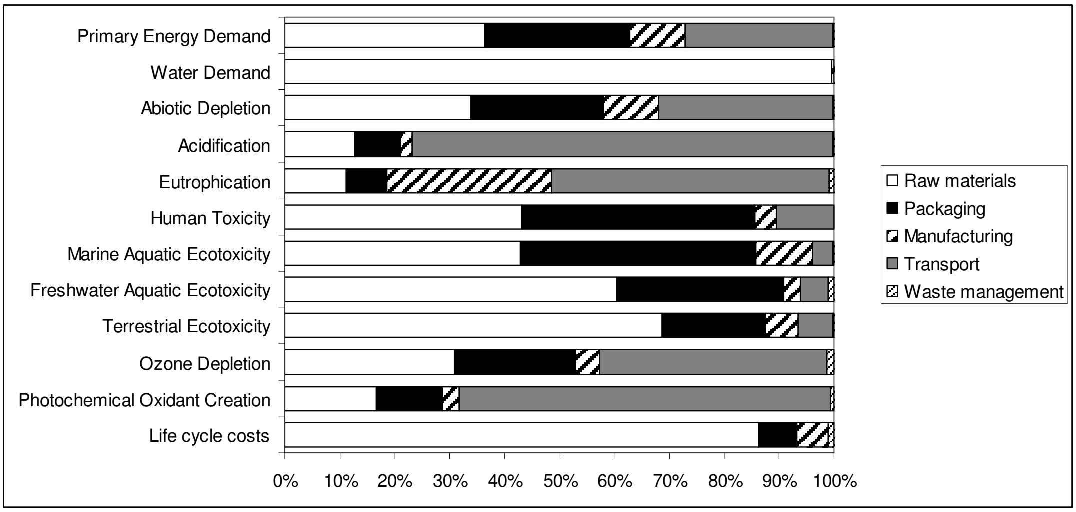

Figure 6-28 Contribution of different life cycle stages to the environmental and economic impacts

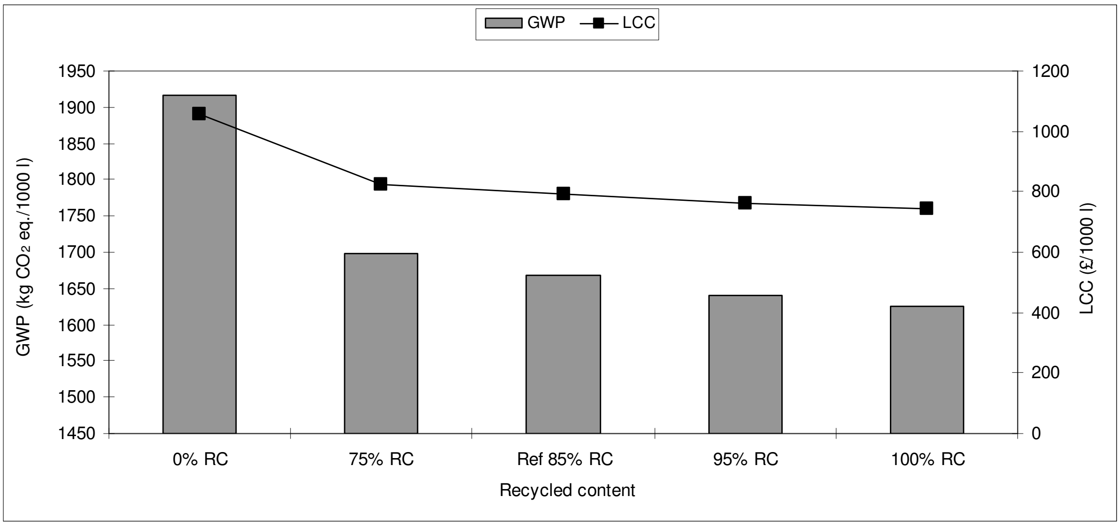

Figure 6-29 Impact of recycled content on global warming potential and life cycle costs

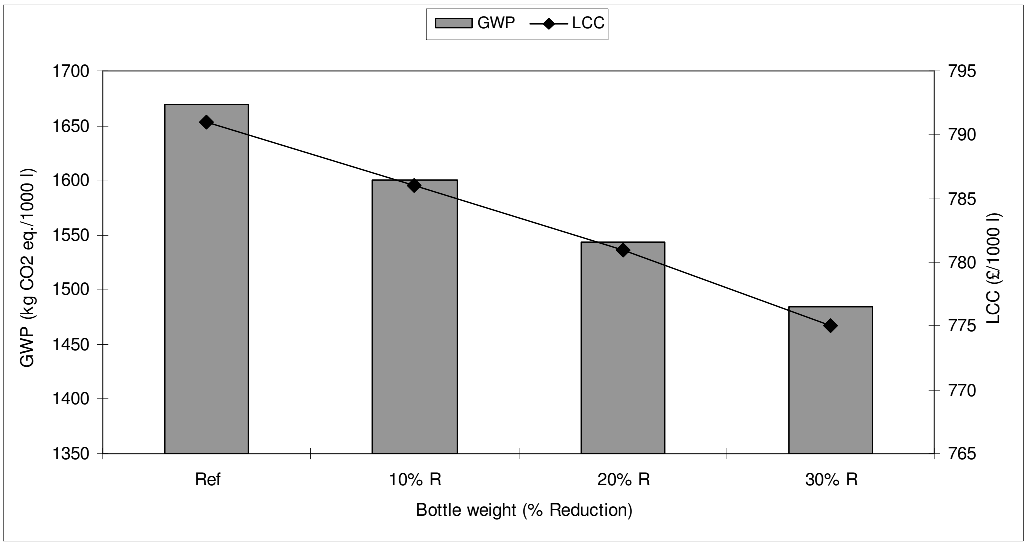

Figure 6-30 Impact of lightweighting on global warming potential and life cycle costs

6.4 Summary

The environmental and economic impacts in the life cycle of wine have been quantified using the LCA and LCC methodologies. The objectives of the case study have been met in that:

- the environmental and economic impacts in the life cycle of wine have been estimated and the hot spots identified for the environmental and economic impacts;
- the life cycle environmental and economic impacts from the wine sub-sector have been estimated based on the findings from the LCA, LCC and a UK market analysis; and
- the impact of improvement options (increasing the recycled content, lightweighting, alternative packaging and alternative agricultural systems) have been estimated for the environmental and economic impacts.

The results of the LCA indicate that raw materials, transport and packaging are the key hot spots for global warming in the life cycle of wine, contributing 35%, 31% and 24%, respectively. This is mainly due to carbon dioxide emissions from production of agricultural chemicals, sea freight and production of glass bottles, respectively. Similar to the results for global warming, raw materials, transport and packaging are the key contributors to other environmental impacts in the life cycle of wine.

The sectoral analysis suggests that consumption of Australian wine in the UK was responsible for over 200,000 tonnes of CO_2 eq. emissions for the period March 2010 to March 2011, representing about 2.3% of the GHG emissions from the whole food and drink sector in the UK.

Results of the sensitivity analysis suggest that increasing the recycled content and lightweighting of glass bottles, as well as use of cartons for packaging of wine have the potential to reduce the environmental impacts in the life cycle of wine. For example, 10% increase in the recycled content would reduce the global warming potential by 2% or 29 kg CO_2 eq. per 1,000 l, amounting to over 4,000 tonnes of CO_2 eq. emissions annually from the wine sector. Similarly, 10% reduction in the weight of the glass bottles would save 57 kg CO_2 eq. emissions per 1,000 l or 9,620 tonnes CO_2 eq. emissions annually from the wine sub-sector. The carton packaging also shows significant environmental improvements compared to the glass bottles. For example the use of cartons instead of glass bottles results in GWP savings of 51% per unit of product. At the sectoral level, a 10% penetration of cartons into the UK market for Australian wines would result in GWP savings of around 5% or 11,700 tonnes CO_2 eq. emissions annually.

Based on the results of the economic analysis, the LCC and VA in the life cycle of wine have been estimated as £791 and £10,662, respectively per 1,000 l of wine. On an annual basis this translates to over £100 million in production costs and revenues of about £1.5 billion for the wine sector.

The sensitivity analysis results also show that increasing the recycled content and lightweighting of glass bottles are beneficial from an economic perspective. For instance, 10% increase in the recycled content would reduce LCC by 4% and increase VA by 0.3%. This translates to increased revenue and savings in production costs of about £4.3 million annually. Similarly, 10% reduction in the bottle weight results in cost savings and added revenue of 0.6% and 0.1%, respectively, amounting to about £700,000 for the wine sector annually.

A comparison of the contributions of the different life cycle stages to the environmental and economic impacts shows that whereas raw materials, transport and packaging are the key hot spots for environmental impacts, economic impacts are mainly due to raw materials. The findings also point to an environmental-economic 'win-win' scenario from increasing the recycled content and lightweighting of glass bottles.

A similar analysis has been carried out for the life cycle of bottled water in the UK. The findings of the environmental and economic analyses are presented in the next chapter.

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7 LIFE CYCLE ASSESSMENT OF ENVIRONMENTAL AND ECONOMIC SUSTAINABILITY OF BOTTLED WATER

The current chapter presents the life cycle assessment of environmental and economic sustainability of bottled water. Life cycle assessment (LCA) and life cycle costing (LCC) are used to quantify the environmental and economic impacts. The life cycle impacts of the bottled water sector are also estimated based on the results of the LCA, LCC and a UK market analysis. The following sections describe the results of the environmental and economic assessment in the life cycle of bottled water and the whole bottled water sector. The environmental aspects are discussed first followed by the economic aspects.

7.1 Life Cycle Assessment

The current LCA study follows the LCA methodology as specified in the ISO 14040/44 standards (ISO, 2006a&b). It starts with definition of the goal and scope of the study, followed by presentation of the inventory data, impact assessment and interpretation of the results. Various sensitivity analyses are also presented.

7.1.1 Goal and scope of the LCA

This LCA case study has three main goals:

i. to estimate the environmental impacts and identify the hot spots in the life cycle of bottled water produced and consumed in the UK;
ii. to analyse how the environmental impacts may be affected by the type and size of different packaging used in the UK: glass bottles (0.75 l) and PET bottles (0.5 l and 2 l); and
iii. to estimate the life cycle impacts from the whole bottled water sub-sector based on the findings from the first two goals of the case study and a UK market analysis.

These packaging sizes have been chosen as the common types of packaging used for bottled water in the UK market. For the first two goals of the study, the functional unit is based on 1,000 litres of bottled water. For the sectoral analysis, the functional unit considers the total annual production and consumption of bottled water in the UK.

The life cycle of bottled water is shown in Figure 7-1. The system boundary of the study is from 'cradle to grave', comprising the following life cycle stages:

- ***Raw materials***: extraction and supply of tap water;
- ***Packaging***: production of primary packaging such as glass and PET bottles, HDPE and aluminium alloy bottle caps, and kraft paper and LDPE labels;
- ***Manufacturing and filling***: electrical energy, steam and compressed air for purification of water and filling in bottles;
- ***Retail***: refrigerated storage at retailer (only as part of sensitivity analysis);
- ***Transport***: transport of packaging, the packaged product and post-consumer packaging waste; and
- ***Waste management***: wastewater treatment of effluents from the manufacturing plant and disposal of post-consumer packaging waste.

The following activities are excluded from the system boundary due to lack of data:

- production of secondary packaging materials; and
- transport of consumers to purchase the product and any storage at consumer.

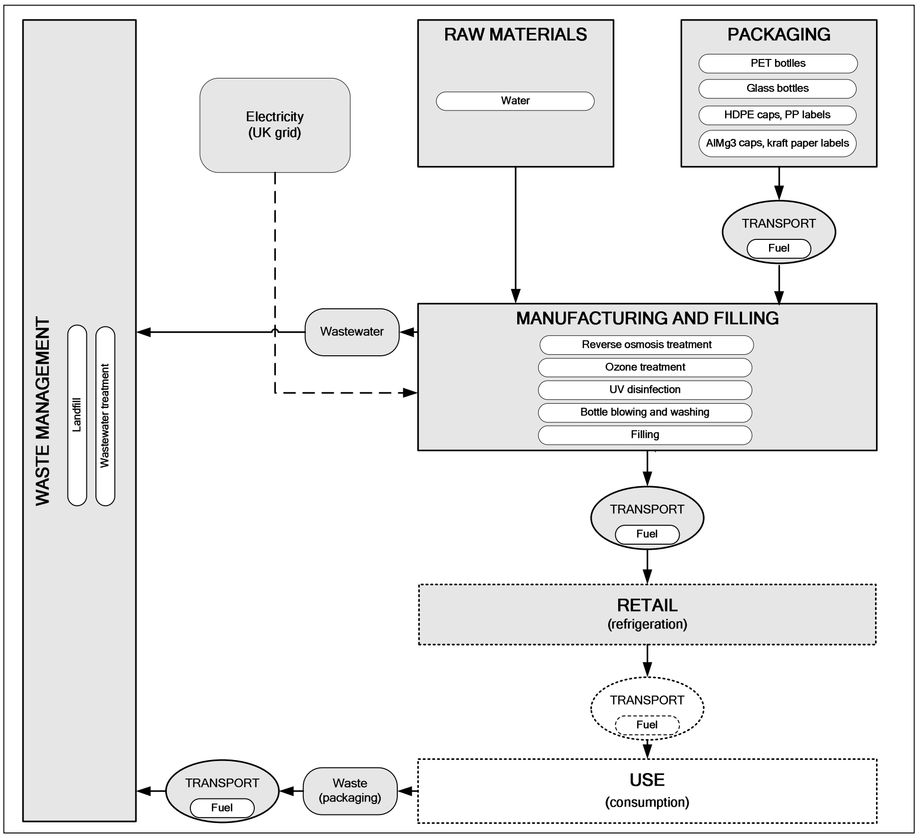

Figure 7-1 The life cycle of bottled water

7.1.2 Inventory data and assumptions

Primary production data have been obtained from literature, including the amounts of water, primary packaging materials, electrical energy, steam and compressed air for purification and packaging. All other data have been sourced from the CCaLC (2011), Ecoinvent (2010) and Gabi (PE, 2010) databases. More detail on the inventory data and their sources is provided below.

7.1.2.1 Raw materials

The amount of water required for filling and washing of bottles has been estimated as 1,260 litres per functional unit (Franklin Associates, 2009). Environmental impacts from the extraction and supply of tap water have been obtained from the Ecoinvent (2010) database.

7.1.2.2 Packaging

The types and weights of the primary packaging materials are summarised in Table 7-1. The types of packaging selected for the study – glass bottles (0.75 l) and PET bottles (0.5 and 2 l) – are typically used for bottled water in the UK. The glass bottles are assumed to contain 85% recycled content based on the UK situation for green glass containers (British Glass, 2009). The tops are assumed to be made from 84% aluminium alloy and 16% LDPE, using data from literature. All components of the PET bottles are made from virgin plastics; tops are made of HDPE and labels of PP based on data from literature (Gujba and Azapagic, 2010).

Table 7-1 Components and weights of the primary packaging materials

Packaging type	Weight (kg /1000 l)	Source of LCI data
Glass bottle (0.75 l)	**800.1**	
Bottle body (85% recycled green glass)	797	Ecoinvent (2010)
Top (84% virgin aluminium alloy, 16% PP)	2.05	ILCD (2010), Gabi (PE, 2010)
Label (kraft paper)	1.04	Gabi (PE, 2010)
PET bottle (0.5 l)	**39.7**	
Bottle body (virgin PET)	34	Ecoinvent (2010)
Top (virgin PP)	5	Ecoinvent (2010
Label (virgin LDPE)	0.7	ILCD (2010), Gabi (PE, 2010)
PET bottle (2 l)	**23.5**	
Bottle body (virgin PET)	21.4	Ecoinvent (2010)
Top (virgin PP)	1.5	Ecoinvent (2010
Label (kraft paper)	0.6	ILCD (2010), Gabi (PE, 2010)

7.1.2.3 Manufacturing

The main process stages involved in bottled water production are described below (Coca Cola, 2010; Franklin Associates, 2009). Water is sourced from the local utility after which it undergoes reverse osmosis to remove impurities. The water then undergoes ozone treatment and ultraviolet (UV) disinfection before it is filled in bottles. The energy and auxiliary materials used at the manufacturing stage are summarised in Table 7-2.

Table 7-2 Energy and materials for manufacturing and filling

Material/Energy	Amount (per 1000 l)	Source of data for amount	Source of LCI data
Electricity (reverse osmosis)	18 MJ	Franklin Associates (2009)	Ecoinvent (2010)
Electricity (ozone treatment)	0.58 MJ	Franklin Associates (2009)	Ecoinvent (2010)
Electricity (UV disinfection)	0.05 MJ	Franklin Associates (2009)	Ecoinvent (2010)
Glass bottle (0.75 l)			
Electricity (filling)	20.5 MJ	CCaLC (2011)	Ecoinvent (2010)
Steam (filling)	8 MJ	CCaLC (2011)	Gabi (PE, 2010)
Compressed air (filling)	6 NM^3	CCaLC (2011)	Ecoinvent (2010)
Water (filling)	556 l	CCaLC (2011)	Ecoinvent (2010)
PET bottle (0.5 l)			
Electricity (filling)	21.1 MJ	CCaLC (2011)	Ecoinvent (2010)
Steam (filling)	20 MJ	CCaLC (2011)	Gabi (PE, 2010)
Compressed air (filling)	3.5 NM^3	CCaLC (2011)	Ecoinvent (2010)
Water (filling)	556 l	CCaLC (2011)	Ecoinvent (2010)
PET bottle (2 l)			
Electricity (filling)	13.1 MJ	CCaLC (2011)	Ecoinvent (2010)
Steam (filling)	15.3 MJ	CCaLC (2011)	Gabi (PE, 2010)
Compressed air (filling)	2.9 NM^3	CCaLC (2011)	Ecoinvent (2010)
Water (filling)	305 l	CCaLC (2011)	Ecoinvent (2010)

7.1.2.4 Retail (refrigeration)

As part of the sensitivity analysis, the global warming potential (GWP) of refrigerated storage at retailer has been considered. The 0.75 l glass and 0.5 l PET bottles have been selected for these analyses as these drink sizes are more commonly refrigerated at the retailer. As shown in Table 7-3 and Table 7-4, the GWP from both electricity consumption and refrigerant leakage have been considered. The following assumptions have been made:

- the refrigerant is assumed to be R404 with GWP of 3860 kg CO_2 eq./kg (IPPC/TEAP, 2005);
- refrigerant charge is estimated as 3.5 kg/kW (van Baxter, 2002; IPPC/TEAP, 2005; Defra, 2007);
- annual refrigerant leakage rate is assumed to be 15% (Tassou et al., 2008; US EPA, 2011);
- total display area of the refrigeration unit is 4.489m^2 (BSI, 2005); and
- the drink is refrigerated for one day (24 hours) before it is sold.

Table 7-3 Global warming potential from electricity consumption at retail

Drink packaged in:	Display cabinet type[a]	Electricity consumption[b] (kWh/m2.day)	Electricity consumption (kWh/m2.h)	Quantity of drink[c] (litres/m2 TDA[d])	Electricity consumption per volume of drink[e] (Wh/l.h)	GWP (g CO2 eq./l.day)
PET bottles (0.5 l)	RVC3	13.8	0.58	106.9	5.4	72
Glass bottles (0.75 l)	RVC3	13.8	0.58	160.5	3.6	48

[a]RVC3 = remote condensing unit, vertical, chilled
[b]Data from Tassou et al. (2008)
[c]Estimated by dividing the total drink volume in the display cabinet (480 litres for PET bottles and 720 litres for glass bottles; estimated by visual examination) by the cabinet TDA (4.489 m^2)
[d]TDA = total display area
[e]Estimated by dividing the cabinet electricity consumption by quantity of drink

Table 7-4 Global warming potential from refrigerant leakage

Drink packaged in:	Volume of drink chilled[a] (l/year)	Refrigerant losses per year[b] (g/l)	Refrigerant losses per litre of drink[c] (g/l.day)	GWP[d] (g/l)
PET bottles (0.5 l)	175,200	1050	0.006	23.13
Glass bottles (0.75 l)	262,800	1050	0.004	15.44

[a]Assuming 480 and 720 litres of PET and glass bottles in the cabinet, respectively; see note c for Table 7-3.
[b]Estimated by multiplying the annual refrigerant losses (15%) by the refrigerant charge (3.5 kg/kW) and power of the refrigerated display unit (2kW).
[c]Estimated by dividing the annual refrigerant losses by the total volume of drink cooled annually.
[d]Estimated by multiplying the refrigerant losses per litre of drink per day by the GWP emission factor for R404A of 3860 kg CO_2 eq./kg R404A.

7.1.2.5 Transport

In assessing the impacts from transport, generic distances of 100 km as well as 40 tonne trucks have been assumed for all transport processes in the system. This includes transport of packaging materials (glass and PET bottles, aluminium alloy and PP closures, kraft paper and LDPE labels), packaged product and post-consumer waste packaging.

7.1.2.6 Waste management

As indicated in Table 7-5, all relevant waste streams have been considered, including in-process effluents from the manufacturing facility as well as post-consumer waste packaging. In-process effluents from the manufacturing facility, consisting of wastewater from washing of bottles, are sent to wastewater treatment. Post-consumer waste packaging, consisting of 15% non-recycled fraction of the glass bottles, aluminium alloy closures, kraft paper labels as well as all components of the PET bottles, are sent to landfill.

Table 7-5 Waste management options

Waste	Amount (kg/1000 l)	Waste management	Source of LCI data
Glass bottle (0.75 l)			
Bottle body (Glass)	119.6	15% landfilled	ILCD (2010), Gabi (PE, 2010)
Closure (84% aluminium, 16% PP)	2.05	Landfilled	Gabi (PE, 2010)
Label (kraft paper)	1.04	Landfilled	ILCD (2010), Gabi (PE, 2010)
Wastewater	556	Wastewater treatment	Gabi (PE, 2010)
PET bottle (0.5 l)			
Bottle body (PET)	34	Landfilled	ILCD (2010), Gabi (PE, 2010)
Closure (PP)	5	Landfilled	ILCD (2010), Gabi (PE, 2010)
Label (LDPE)	0.7	Landfilled	ILCD (2010), Gabi (PE, 2010)
Wastewater	556	Wastewater treatment	Gabi (PE, 2010)
PET bottle (2 l)			
Bottle body (PET)	21.4	Landfilled	ILCD (2010), Gabi (PE, 2010)
Closure (PP)	1.5	Landfilled	ILCD (2010), Gabi (PE, 2010)
Label (kraft paper)	0.6	Landfilled	ILCD (2010), Gabi (PE, 2010)
Wastewater	305	Wastewater treatment	Gabi (PE, 2010)

7.1.2.7 Data quality

Using the data quality assessment approach presented in Chapter 3, the LCA data quality has been assessed for the bottled water systems. The overall LCA data quality for the bottled water system has been estimated as ‘High’ for the different packaging systems considered in this work. More detail on the data quality assessment is provided in Appendix 3, section A3.4.

7.1.3 Impact assessment and interpretation

The Gabi 4.3 LCA software has been used to model the system. The CML 2001 (Guinee et al., 2001) impacts characterisation method has been used to estimate the environmental impacts. The global warming potential is discussed first followed by the other environmental impacts.

7.1.3.1 Global warming potential (GWP)

The results for the GWP are shown in Figure 7-2. The highest GWP (388 kg CO_2 eq. per 1,000 l) is found for the glass packaging and the lowest (112 kg CO_2 eq.) for the 2 l PET bottle. Water packaged in 0.5 l PET bottles has the GWP of 180 kg CO_2 eq. per functional unit. By comparison, the GWP of carbonated soft drink packaged in glass, 0.5 l and 2 l PET bottles are 555 kg CO_2 eq., 293 kg CO_2 eq. and 151 kg CO_2 eq., respectively. The difference in GWP between similar types of packaging can be explained by the contribution from the ingredients used in production of carbonated soft drinks. For example, the GWP for the carbonated soft drink packaged in 2 l PET bottles would be similar to that of bottled water in similar packaging if the GWP from production of ingredients was subtracted (111 and 112 kg CO_2 eq./1,000 l).

As can also be seen from Figure 7-2, packaging is the major hot spot, contributing between 82% (2 l PET bottle) and 93% (glass bottle) of the total GWP. This is mainly due to carbon dioxide emissions from manufacture of the primary packaging: 83%, 72% and 69% of the total GWP for the glass bottles, 0.5 l PET and 2 l PET, respectively. The GWP for the 0.5 l PET bottle is also higher than that of the 2 l PET bottle by about 38% due to the higher amount of packaging materials required to package a similar volume of water.

The contribution to GWP from the other life cycle stages – transport, waste management, manufacturing and raw materials – is negligible, each accounting for less than 7% for all the packaging types.

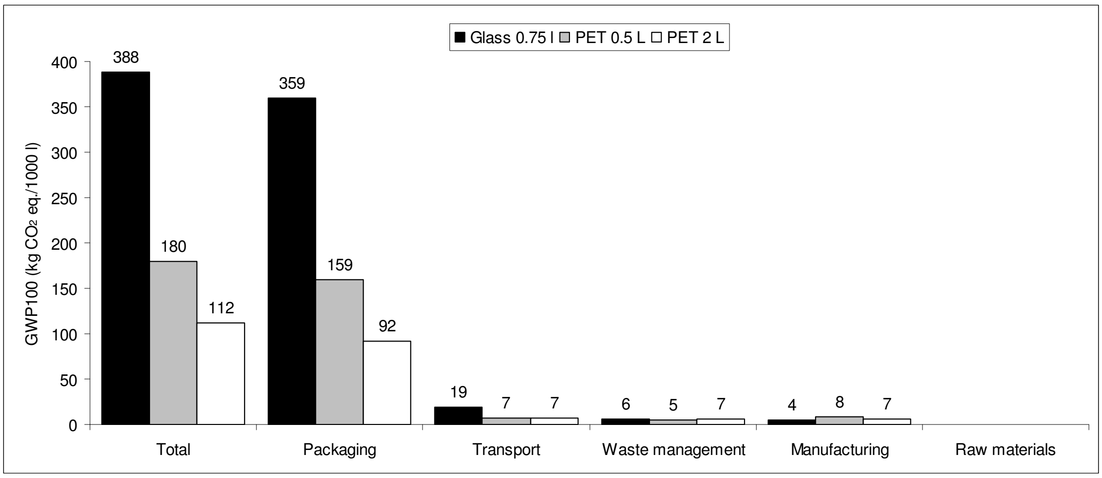

Figure 7-2 Global warming potential of bottled water for different types of packaging also showing the contribution of different life cycle stages

7.1.3.2 Impact on GWP of refrigerated storage at retailer

A further analysis has been carried out to assess the impact on GWP of refrigerated storage at the retail stage. Only the glass and 0.5 l PET bottle are considered as the drink sizes that are often refrigerated by retailers in the UK. The results are shown in Figure 7-3. As shown, the refrigerated storage adds 16% to the total GWP for the glass bottles and 53% to the total GWP for the PET bottles. Due to the significant contribution from refrigerated storage to GHG emissions, refrigerated storage at retailer should be avoided. However, due to consumer perception and taste preference, retailers would be reluctant to discontinue this practice.

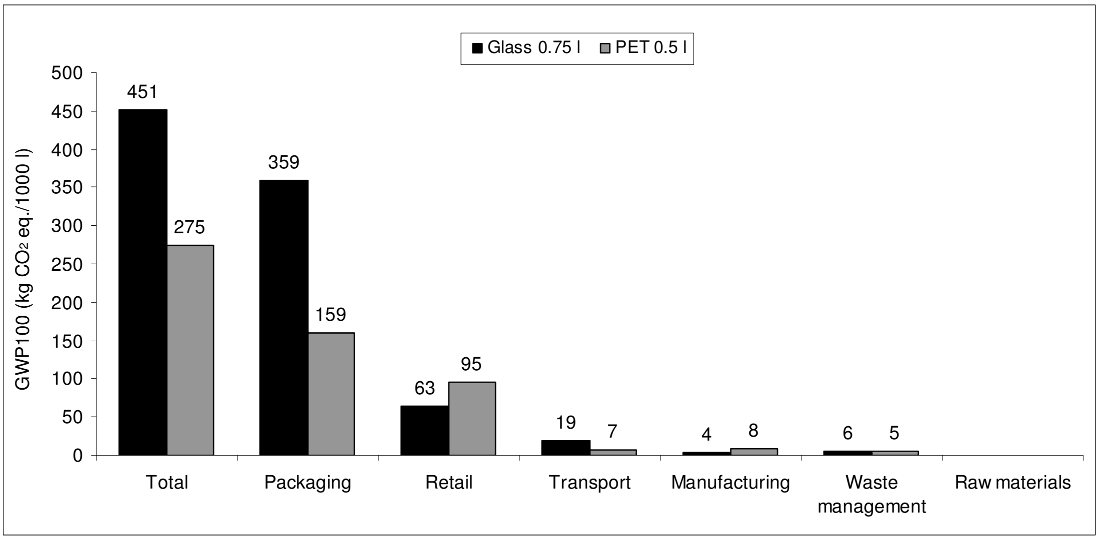

Figure 7-3 Contribution to global warming of retail (refrigerated storage) of bottled water for glass bottles (0.75 l) and PET bottles (0.5 l)
[The retail stage comprises refrigerated storage.]

7.1.3.3 Impact on GWP of PET recycling rates

Given the relative importance of the packaging stage to the environmental impacts, the effect of increased recycling rates for the PET bottles has been assessed. The study by Amienyo et al. (2012) estimates that GWP savings of around 33% can be achieved by increasing PET recycling rates from 24% (as assumed in the current study) to 40%. Applying this estimate to the current study would reduce the GWP of bottled water packaged in 0.5 l PET bottles from the current estimate of 180 kg CO_2 eq./1,000 l to 121 kg CO_2 eq./1,000 l. Therefore, there is a compelling case for increasing the recycling rate for PET in the bottled water sub-sector, as well as other sectors where PET is utilised.

7.1.3.4 Impact on GWP of bottle lightweighting

Figure 7-4 shows the effect of lightweighting on GWP in the life cycle of bottled water, estimated as part of the sensitivity analysis. As shown in Figure 7-4, 10% reduction in the bottle weights results in GWP savings at the systems level of 9%, 8% and 6% for the 0.75 l glass, 0.5 l PET and 2 l PET bottles, respectively. At the sub-sectoral level, 10% reduction in the weights of the bottles results in GWP savings of around 7% or 24,000 tonnes CO_2 eq. per annum. Similar to the previous case studies of beer and red wine presented in the preceding chapters (Chapters 5 and 6), these findings help to establish lightweighting as a viable option of for environmental improvements in the beverage sector.

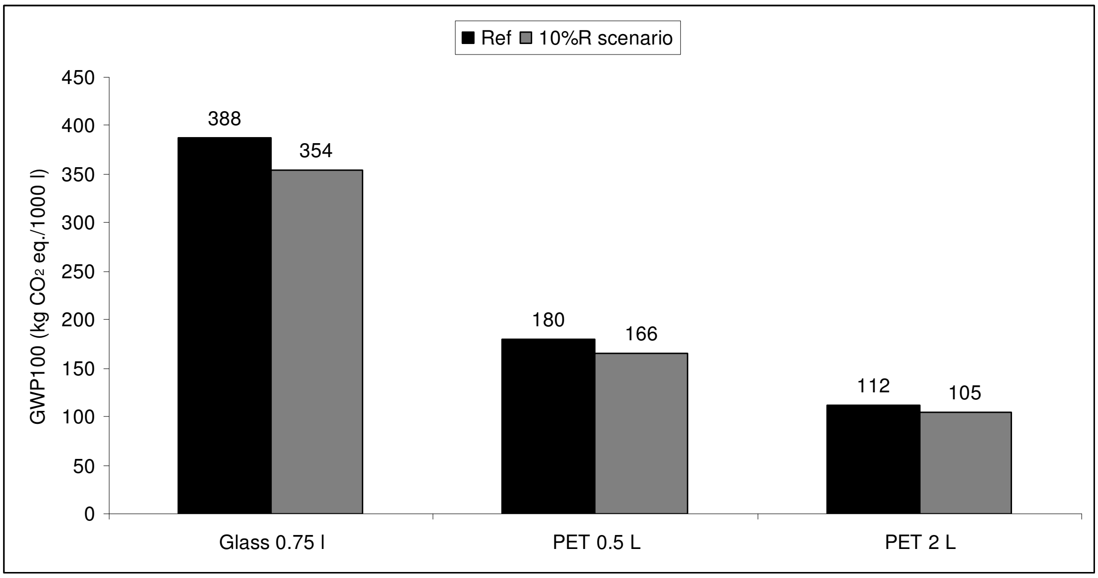

Figure 7-4 Effect of lightweighting on the global warming potential per 1,000 litres of bottled water

7.1.3.5 Comparison of GWP results with other studies

The results for GWP have been compared in Figure 7-5 to five other studies of bottled water (Jungbluth, 2006; Cerelia, 2008; SpA, 2010; Nestle, 2010; Coop, 2011). The highest GWP can be found for bottled water packaged in glass bottles, ranging from 388 kg CO_2 eq. to 600 kg CO_2 eq. per 1,000 l mainly due to the energy required for manufacturing the glass bottles. It can also be seen that, similar to the findings in the current study, the GWP for the 0.5 l PET bottle (ranging from 180 – 235 kg CO_2 eq./1,000 l) is higher than that of the 2 l PET (112 – 135 kg CO_2 eq./1,000 l) bottle due to the higher amount of packaging material required for a similar volume of water. Generally, the findings of the current study show good agreement with the other studies shown in Figure 7-5, with marginal differences within the packaging categories. The difference in the results may be attributed to several factors including stages that have been included and excluded from the analyses and the fact that the products are manufactured in different geographical regions with unique energy mixes (e.g. Italy, UK, USA and Switzerland), different production scales and different levels of efficiency, different bottle weights, as well as whether the product is carbonated or not. For example, within the 0.5 l PET category, the highest GWP (199 kg CO_2

eq./1,000 l) is found for the product which contains carbon dioxide and has a higher bottle weight (54 g/l compared to the current study of 39.2 g/l).

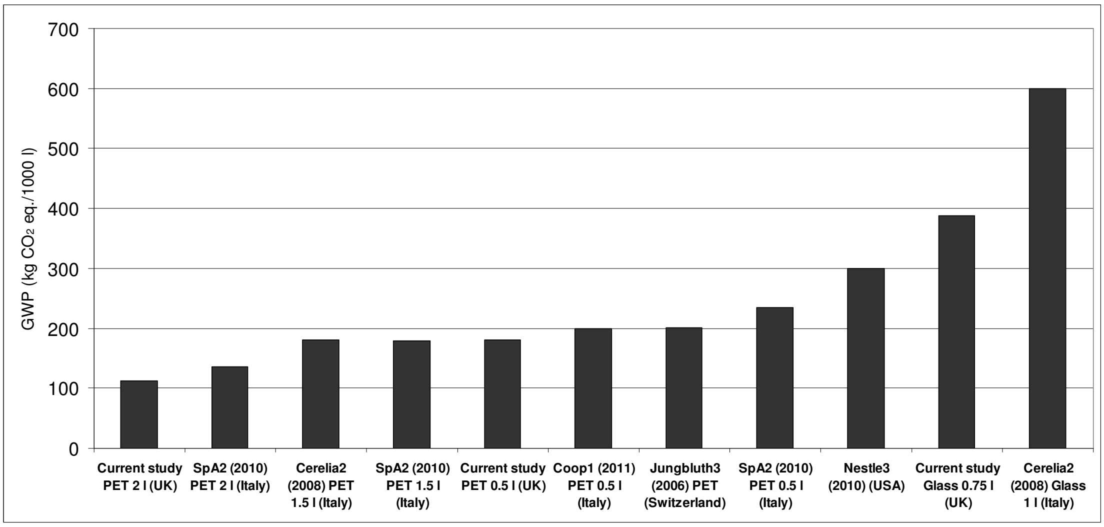

Figure 7-5 Comparison of global warming potential of bottled water with other studies

[[1]Sparkling water includes carbon dioxide; [2]Includes impact of secondary packaging; [3]Unspecified packaging type and size.]

7.1.3.6 Other environmental impacts

As shown in Figure 7-6, water packaged in the 2 l PET bottle has the lowest impacts for the ten environmental impacts: primary energy demand (PED), abiotic depletion (ADP), acidification (AP), eutrophication (EP), human toxicity (HTP), marine and freshwater aquatic ecotoxicity (MAETP and FAETP), terrestrial ecotoxicity (TETP), ozone depletion (ODP) and photochemical oxidant creation (POCP) potentials.

The glass bottle, on the other hand, is the worst option for all the environmental impacts except TETP. The 0.5 l PET bottle has the highest TETP, mainly due to atmospheric emissions of chromium from manufacturing of PET bottles. The ODP from the glass bottles is relatively high relative to the PET bottles (4.5 times higher than the next worst option, 0.5 l PET) – this is due to atmospheric emissions of non methane volatile organic compounds (NMVOC) from manufacturing of glass bottles.

The contribution of the different life cycle stages to the environmental impacts are shown in Figure 7-7 to Figure 7-9. Similar to the GWP, the packaging stage is the major hot spot for all the impacts. For all the environmental impacts, production of packaging accounts for 84 – 99%, 84 – 98% and 77 – 96% for the glass, 0.5 l PET and 2 l PET bottles, respectively. This is mainly due to production of energy (electricity and steam) and emissions from manufacturing of the primary packaging.

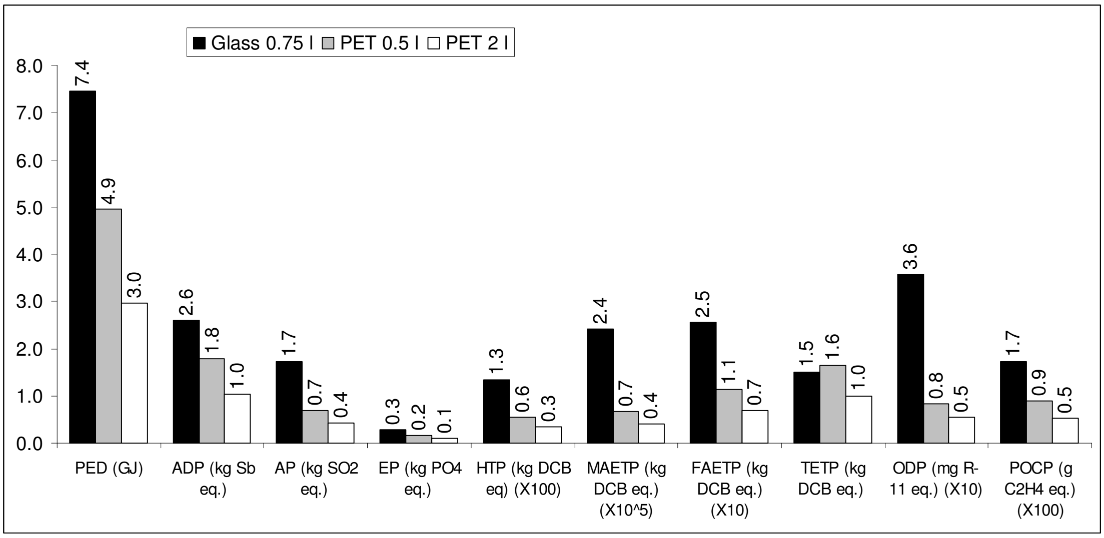

Figure 7-6 Environmental impacts in the life cycle of bottled water (GWP not shown)

[The scaled values should be multiplied with the factor shown in brackets against the relevant impact to obtain the original values.]

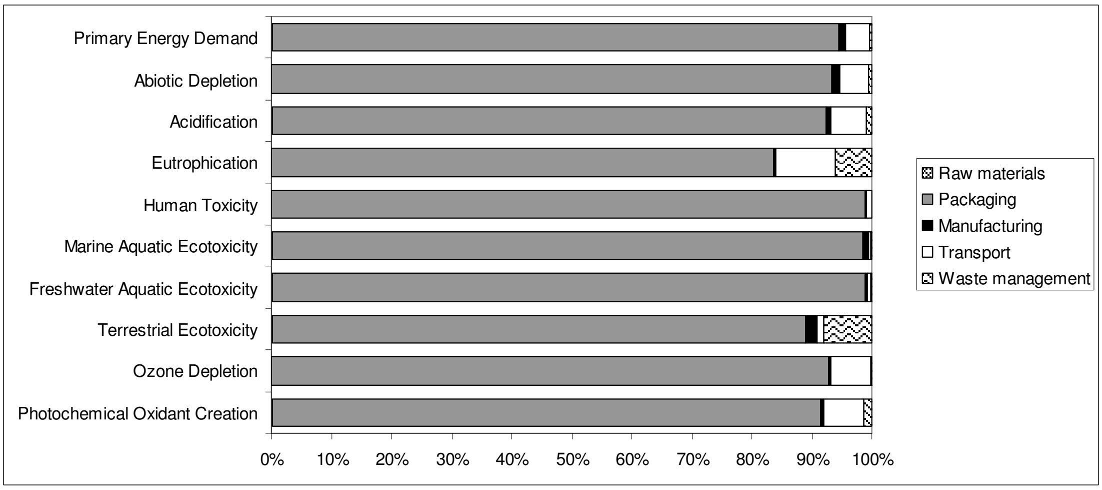

Figure 7-7 Contribution of different life cycle stages to the environmental impacts for the 0.75 l glass bottle

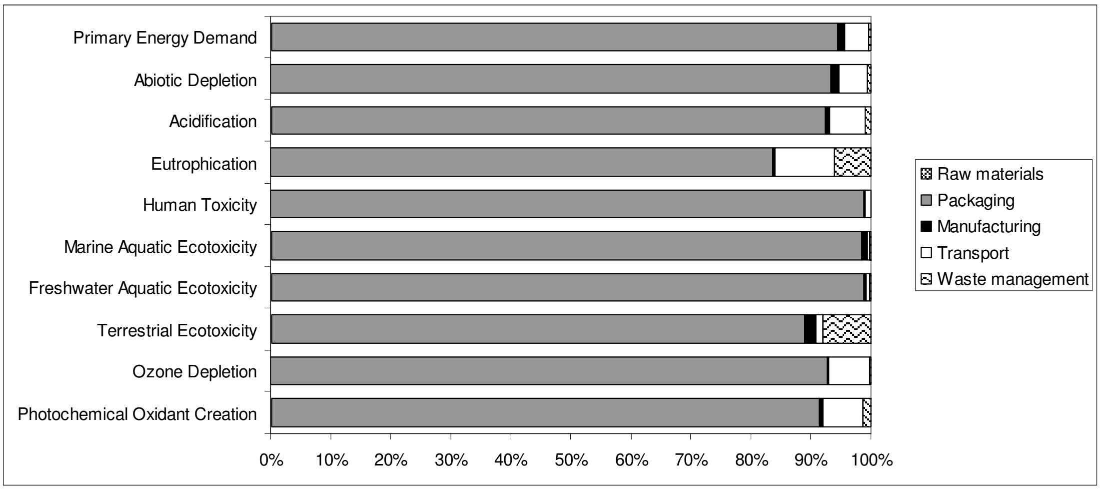

Figure 7-8 Contribution of different life cycle stages to the environmental impacts for the 0.5 l PET bottle

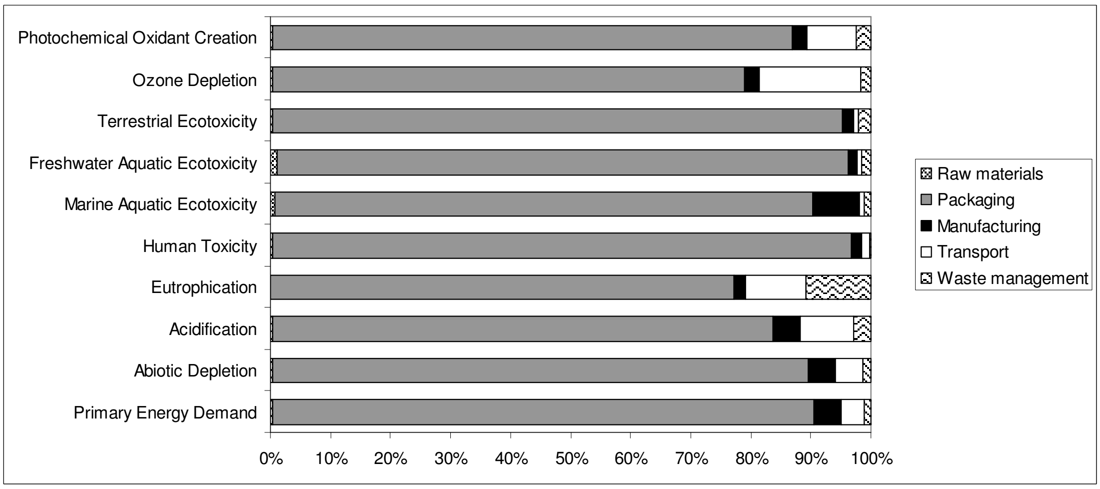

Figure 7-9 Contribution of different life cycle stages to the environmental impacts for the 2 l PET bottle

7.1.3.7 Environmental impacts at the sectoral level

In order to estimate the life cycle impacts from the bottled water sub-sector in the UK, the findings of the study have been extrapolated for the total production and consumption of about 2.1 billion litres consumed in 2010 (BSDA, 2011). Of this amount, 93% was packaged in plastics and 7% in glass packaging. From Figure 7-10, it can be seen that the bottled water sector was responsible for about 334,842 tonnes of CO_2 eq. emissions in 2010. This represents about 3% of GHG emissions from the food and drink sector[28]. Although the estimates for the GHG emissions are not directly comparable as in one case they represent the life cycle emissions (for the bottled water sector) and mainly direct emissions (food and drink sector), they are nevertheless an indication of the significance of the sector's contribution to GHG emissions in the UK.

While it is difficult to put the other environmental impacts into context, it can be seen from Figure 7-11 that marine aquatic ecotoxicity and ozone depletion potentials from the glass bottles are disproportionately higher than their market share would suggest. This is mainly due to the high atmospheric emission of hydrogen fluoride and volatile organic compounds, respectively.

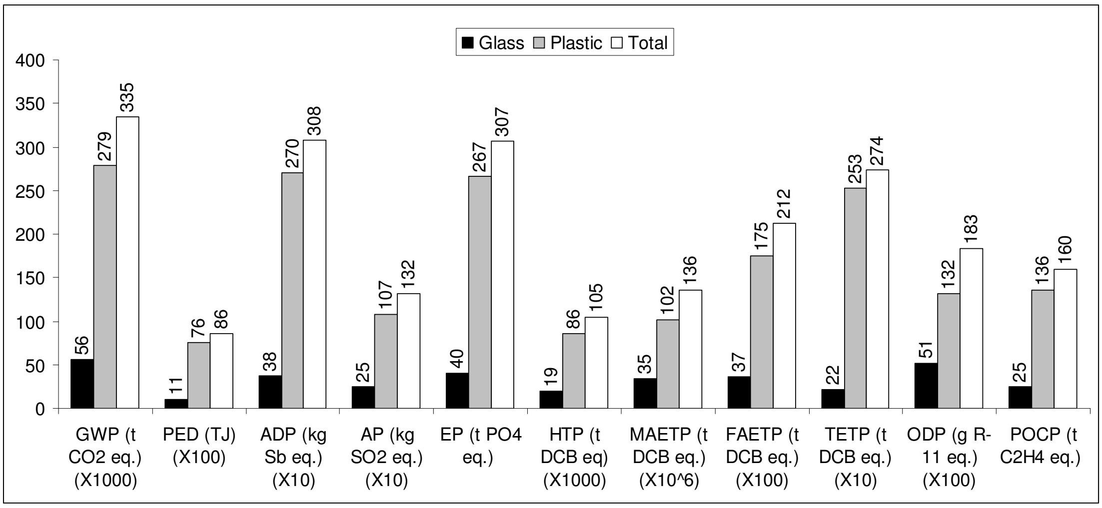

Figure 7-10 Life cycle environmental impacts of bottled water in the UK
[The scaled values should be multiplied with the factor shown in brackets against the relevant impact to obtain the original values.]

[28] Estimated based on the total UK GHG emissions of 582.4 million tonnes of CO_2 eq. (DECC, 2011) and the stated contribution by FDF (2008) of the food and drink sector of 2% to total UK GHG emissions.

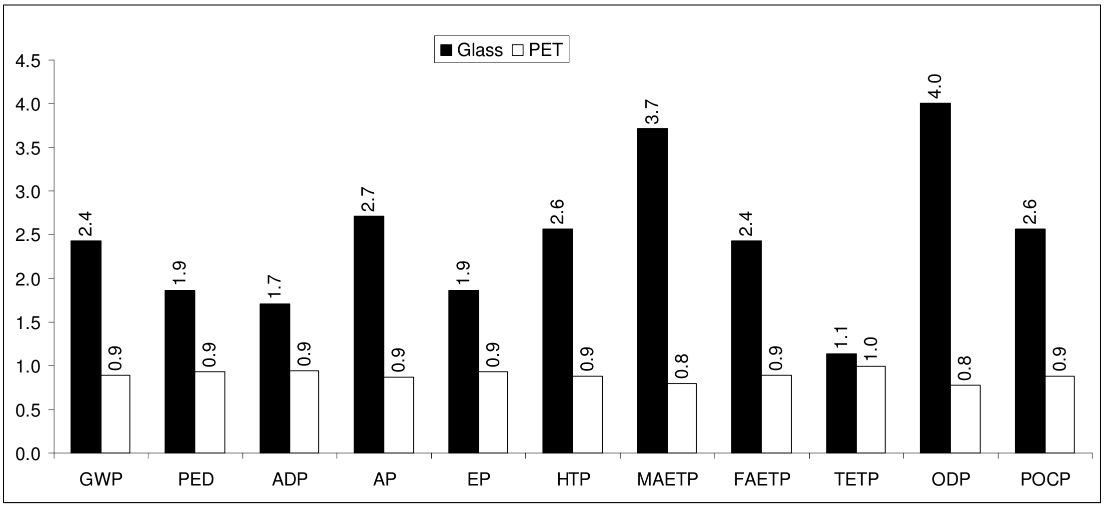

Figure 7-11 Comparison of environmental impacts for different types of packaging relative to their market share

[The values represent the ratio of the impact for each packaging type and its market share of 7% for glass bottles and 93% for PET bottles.]

7.1.3.8 Comparison of GWP results with tap water

An additional analysis has been carried out which compares the environmental impacts of tap water and bottled water. The environmental impacts associated with the extraction, treatment and supply of tap water have been sourced from the Ecoinvent (2010) database. As shown in Figure 7-12, the life cycle environmental impacts arising from the production and supply of tap water are significantly lower than that of bottled water packaged in 2 l PET bottles by factors ranging from 135 (FAETP) to 550 (ADP and EP). The difference in the impacts arise mainly from production of the packaging materials (and all associated background processes) as well as production of electricity energy for further treatment and filling of bottles at the manufacturing facility. These findings illustrate the significance of the bottled water sub-sector both in the UK and on a global scale.

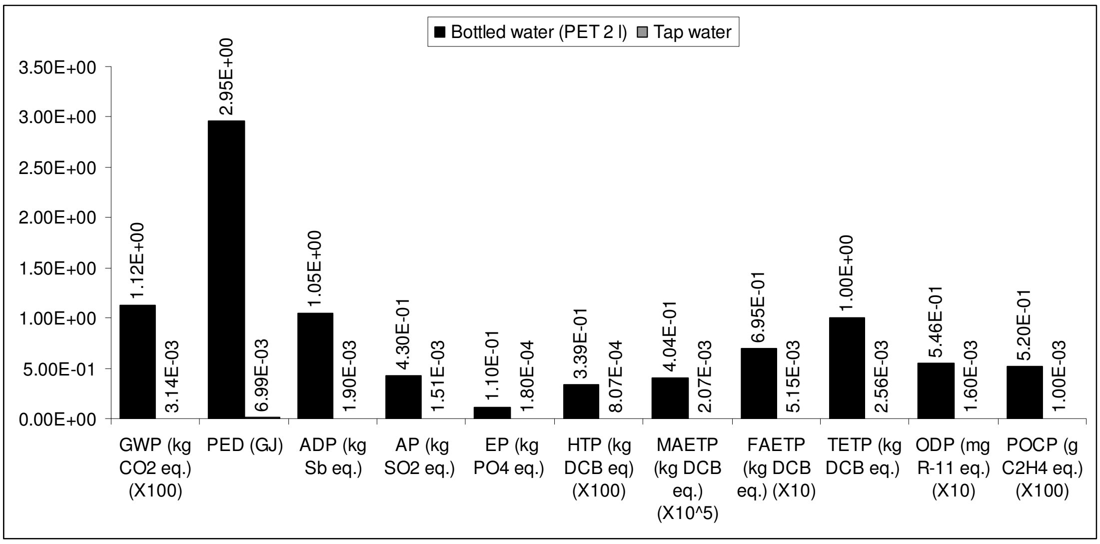

Figure 7-12 Life cycle environmental impacts of bottled water and tap water
[The scaled values should be multiplied with the factor shown in brackets against the relevant impact to obtain the original values.]

7.2 Life cycle economic assessment

Two aspects are considered within the life cycle economic assessment: life cycle costs and value added. The methodology follows that used for the LCA as far as possible; further details on the LCC and VA methodologies can be found in Chapter 3. The life cycle costs are considered from the perspective of the manufacturer, consumer and the government.

7.2.1 Goal and scope

The current LCC study has three main goals:

i. to estimate the life cycle costs and value added, and identify the hot spots in the life cycle of bottled water produced and consumed in the UK;
ii. to analyse how the economic aspects may be affected by the type and size of different packaging used in the UK: glass bottles (0.75 l) and PET bottles (0.5 l and 2 l); and
iii. to estimate the life cycle costs and value added for the whole bottled water sub-sector based on the findings from the first two goals of the study and a UK market analysis.

Similar to the LCA, the functional unit is based on 1,000 litres of bottled water while the sub-sectoral analysis considers total annual production and consumption of bottled water in the UK.

7.2.2 Inventory data and assumptions

The life cycle inventory data are based on the LCA data presented in section 7.1.2. Primary production cost data have been sourced from literature, including the amounts of water, packaging materials, electricity, steam and compressed air for manufacturing of bottled water. It is assumed that freight costs are included in the material costs; therefore the cost impact of each material in the life cycle includes transport. It is also assumed that the manufacturer bears the costs of raw materials, packaging, manufacturing and waste management of in-process waste while the consumers bear the costs for disposal of post-consumer waste packaging. More detail on the cost data is provided below.

7.2.2.1 Raw materials

The only raw material considered in the current case study is water supplied from the public utility. The cost of water has been obtained from a water supply company in the UK (United Utilities, 2010).

7.2.2.2 Packaging

The costs of the packaging materials in the life cycle of bottled water are summarised in Table 7-6. It is important to note that the material costs shown do not include the costs associated with fabrication of the final packaging (glass and PET preforms). However, the energy for filling includes blowing of PET preforms to make the bottles.

Table 7-6 Costs and sources of packaging materials

Packaging type	Cost (£/1000 l)	Source of cost data
Glass bottle (0.75 l)		
Primary glass (15% non-recycled content)[a]	46.3	Ali express (2011)
Recycled glass cullet (85% recycled content)[b]	4.4	WRAP (2011)
Aluminium alloy (closure)[c]	2.8	LME (2011)
Kraft paper (label)[d]	1.0	FOEX indexes (2011)
PET bottle (0.5 l)		

PET (bottle body)[e]	22.1	WRAP (2011)
PP (closure)[f]	1.9	Plasticsinfomart.com (2011)
LDPE (label)[g]	0.4	WRAP (2011)
PET bottle (2 l)		
PET (bottle body)[e]	22.1	WRAP (2011)
PP (closure)[f]	1.9	Plasticsinfomart.com (2011)
Kraft paper (label)[d]	0.2	FOEX indexes (2011)

[a]Price per kg of white container glass.
[b]Average price per kg of recycled green glass cullet assumed.
[c]Seller price per kg of primary aluminium in the commodity market.
[d]Price per kg of unbleached kraft paper in the commodity market.
[e,f,g]Market prices for primary PET, PP and LDPE in the UK market.

7.2.2.3 Manufacturing

The costs of inputs for water treatment and filling in bottles are summarised in Table 7-7. Wastewater treatment of effluents from the manufacturing and bottling plant has been included in the manufacturing stage as these costs are accrued by the manufacturer.

Table 7-7 Costs of manufacturing inputs in the life cycle of bottled water

Material/Energy	Cost (£/1000 l)	Source of cost data
Electricity (water treatment)	0.7	Electricityprices.org.uk (2011)
Glass bottle (0.75 l)		
Electricity (filling)	0.8	Electricityprices.org.uk (2011)
Water (washing and filling)	0.8	United Utilities (2011)
Effluents from plant	0.2	Scottish Water (2011)
PET bottle (0.5 l)		
Electricity (filling)	0.8	Electricityprices.org.uk (2011)
Water (washing and filling)	0.8	United Utilities (2011)
Effluents from plant	1.7	Scottish Water (2011)
PET bottle (2 l)		
Electricity (filling)	0.5	Electricityprices.org.uk (2011)
Water (washing and filling)	0.8	United Utilities (2011)
Effluents from plant	1.7	Scottish Water (2011)

7.2.2.4 Waste management

The waste disposal costs for the post-consumer waste packaging are summarised in Table 7-8. It is assumed that the non-recycled component of the glass bottles, as well as all other packaging materials, is landfilled at the end of life.

Table 7-8 Costs of waste management options in the life cycle of bottled water[a]

Waste	Cost (kg/1000 l)	Waste management
Glass bottle (0.75 l)		
Glass bottle	6.9	15% landfilled
Aluminium alloy closure	0.2	Landfilled
Kraft paper label	0.2	Landfilled
PET bottle (0.5 l)		
PET bottle	2.6	Landfilled
PP closure	0.3	Landfilled
LDPE label	0.1	Landfilled
PET bottle (2 l)		
PET bottle	1.3	Landfilled
PP closure	0.2	Landfilled
Kraft paper label	0.03	Landfilled

[a]All cost data for waste disposal from WRAP (2011).

7.2.2.5 Consumer costs

It is assumed that the consumer bears the costs of disposal of post-consumer packaging waste through taxes paid for waste collection and disposal services. These are shown as landfill costs in Table 7-8. The retail price of the product, which has been used to estimate VA, can also be classified as consumer costs. The retail prices are shown in Table 7-9.

Table 7-9 Average retail price of bottled water in the UK

Type of packaging for product	Average UK retail price (£/1000 l)[a]
Glass bottle (0.75 l)	1,286
PET bottle (0.5 l)	670
PET bottle (2 l)	420

[a]Data based on the average price of three brands of bottled water in the major UK retail outlets (Asda, Tesco, Sainsbury's, Waitrose and Ocado): Buxton, Highland Spring and Volvic). Data from January 2012.

7.2.2.6 Data quality

Following the data quality assessment approach presented in Chapter 3 of this work, the data quality for the LCC has been assessed. The overall LCC data quality for the bottled water system has been assessed as 'Medium' for the different packaging systems. More detail on the data quality assessment is provided in Appendix 4, section A4.4. An important limitation of the study is the assumption that market prices are equivalent to supply chain costs. Market prices have been used in the study due to the lack of supply chain-specific data (confidentiality). However, the data quality analysis provides an indication of the level of confidence that can be placed in the results.

7.2.3 Life cycle economic impacts and interpretation

The results of the LCC are discussed first followed by the VA results. Following this, the two economic aspects as discussed for the bottled water sub-sector.

7.2.3.1 Life cycle costing (LCC)

The results of the LCC are given in Figure 7-13. The LCC results shown represent the production costs of bottled water accrued by the manufacturer, excluding the costs of post-consumer waste packaging disposal. However, post-consumer waste disposal accounts for 2%, 9% and 3% of the total LCC for the glass, 0.5 l PET and 2 l PET bottles, respectively. The highest LCC (£60 per 1,000 l of bottled water) is found for the glass bottle while water packaged in 0.5 l and 2 l PET bottles are similar (£30 per functional unit). However when disposal of post-consumer waste packaging is taken into account, water packaged in the 0.5 l PET bottle has a marginally higher LCC than water packaged in the 2 l PET bottle (£33 and £31, respectively).

As can be seen in Figure 7-13, packaging is the major hot spot in the life cycle of bottled water, contributing 90% of the LCC for the glass bottle, and 80% for the 0.5 l and 2 l PET bottles. The LCC from packaging is mainly due to the glass and PET bottles, accounting for 93%, 91% and 92% of the LCC from packaging for the glass, 0.5 l PET and 2 l PET bottles, respectively.

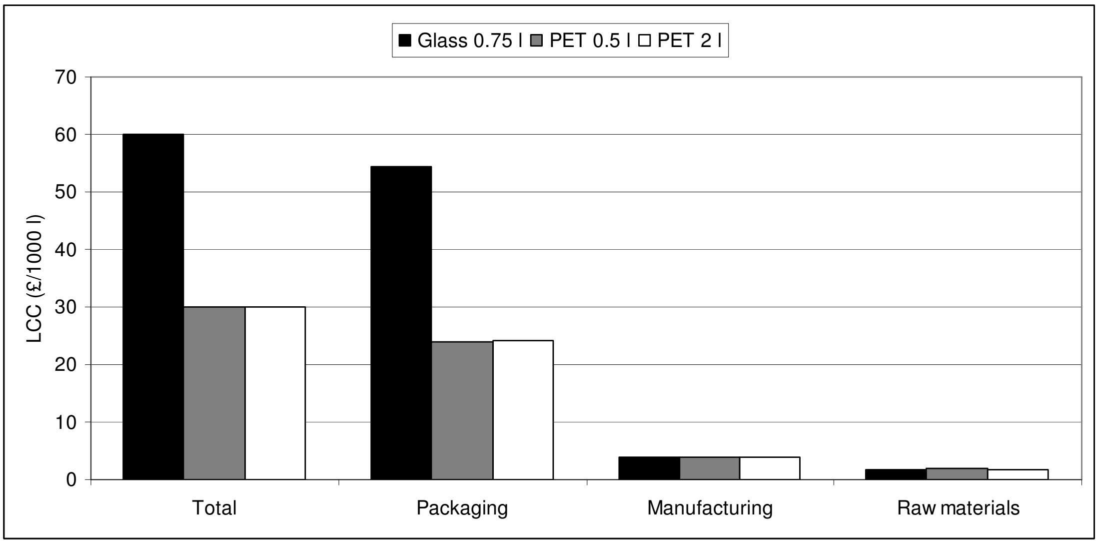

Figure 7-13 Life cycle costs of bottled water for different types of packaging also showing the contributions from the life cycle stages

7.2.3.2 Value added (VA)

The results for the VA assessment are shown in Figure 7-14 for the different types of packaging considered in the current study. The VA represents the difference between the retail prices, as shown in Table 7-9, and the LCC. As can be seen in Figure 7-14, water packaged in the glass bottle has the highest VA (£1,226 per 1,000 l) despite having the highest LCC. The lowest VA is observed for the 2 l PET bottle (£390 per 1,000 l) while water packaged in the 0.5 l PET bottle has the VA of £640 per functional unit. The significant difference between the VA for the glass and PET bottles is mainly due to the significantly higher quantity and cost of glass compared to PET. For example, the glass bottle system requires 797 kg of glass per 1,000 l compared to 34 kg and 21 kg for the 0.5 l and 2 l PET, respectively (see Table 7-1 and Table 7-6).

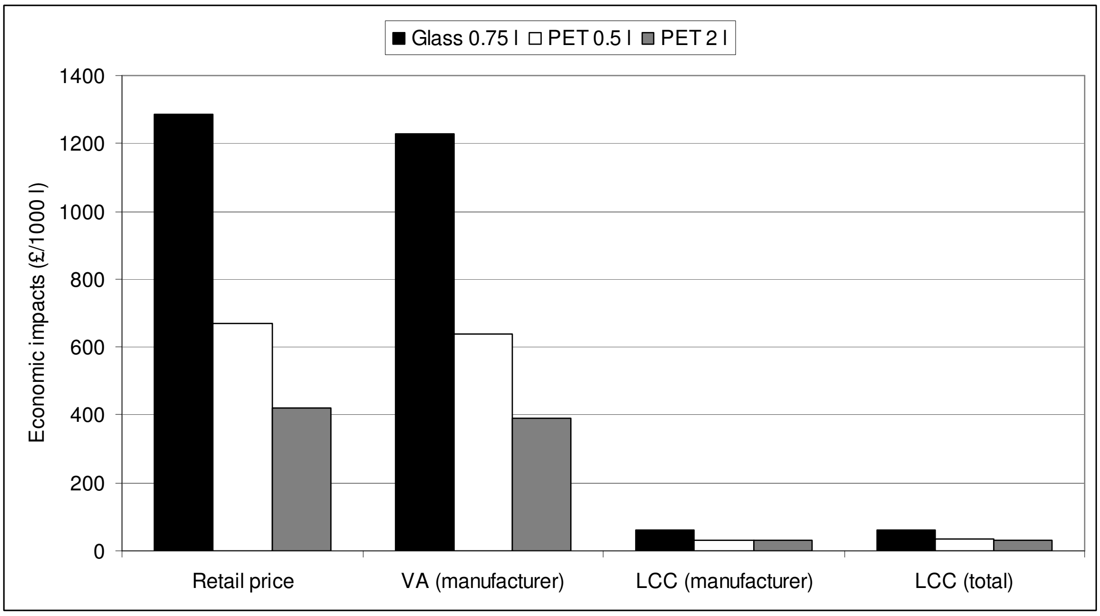

Figure 7-14 Value added of bottled water for different types of packaging per 1000 litres of bottled water also showing the retail price and life cycle costs [VA (manufacturer) – value added accrued by the manufacturer. LCC (manufacturer) – life cycle costs for the manufacturer (minus costs for disposal of post-consumer packaging waste). LCC (total) – total life cycle costs including disposal of post-consumer packaging waste.]

7.2.3.3 Life cycle costs and value added at the sectoral level

Similar to the LCA, the LCC and VA from the bottled water sub-sector have been estimated by extrapolating the LCC and VA results for the total production and consumption of 2.1 billion litres in 2010 (BSDA, 2011). Considering the total consumption and consumer penetration by type of packaging (93% in plastics and 7% in glass bottles), the LCC and VA for the bottled water sector are shown in Figure 7-15. It can be seen that production and consumption of bottled water in the UK was responsible for about £66 million in life cycle costs in 2010. The value added is estimated to be about £1.2 billion for the reference year. This amounts to approximately 0.1% of the UK GDP[29].

[29] Based on the stated UK GDP of £1,392,634 million for 2009 (Key Note, 2011: sourced from Economic and Labour Market Review, November 2010, National Statistics website.

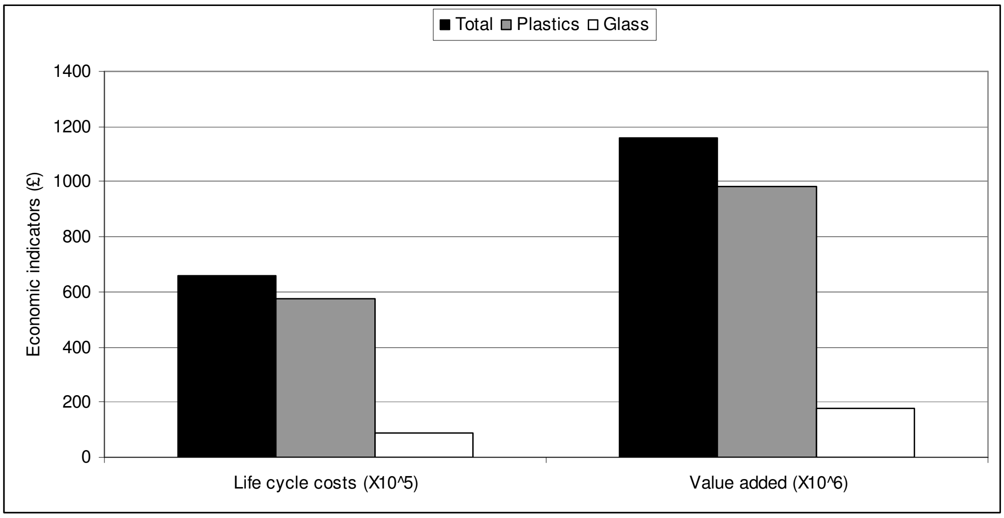

Figure 7-15 Life cycle economic impacts of bottled water in the UK

7.3 Comparison of environmental and economic sustainability

The contribution of the different life cycle stages to the environmental and economic impacts are shown in Figure 7-16 to Figure 7-18. The combination of environmental and economic aspects facilitates the identification and comparison of environmental and economic hot spots in the life cycle of bottled water. It can be observed that the environmental and economic impacts are dominated by the packaging stage, with minimal contributions from the other life cycle stages. The packaging stage should therefore, be the focus of sustainability improvement initiatives in the bottled water sub-sector.

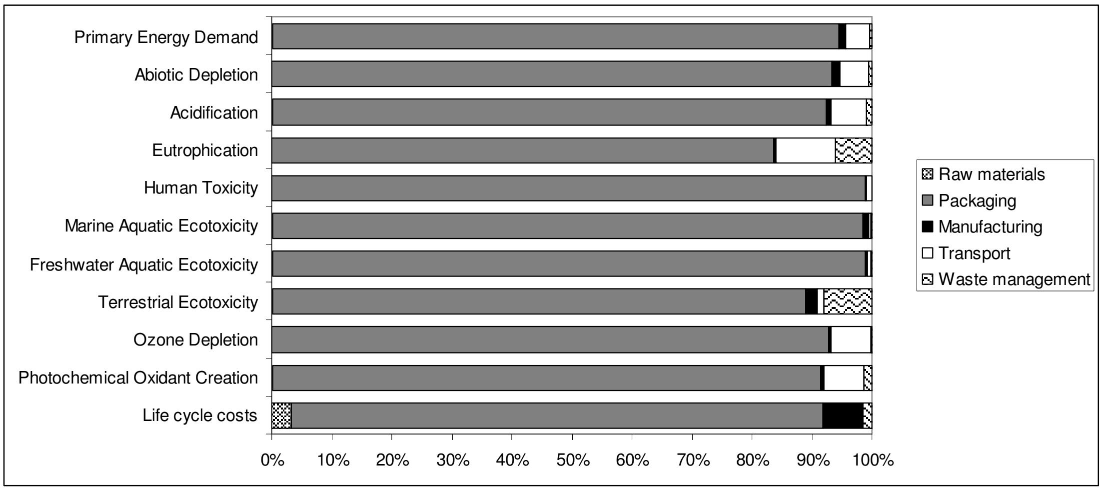

Figure 7-16 Contribution of different life cycle stages to environmental and economic impacts for the 0.75 l glass bottle

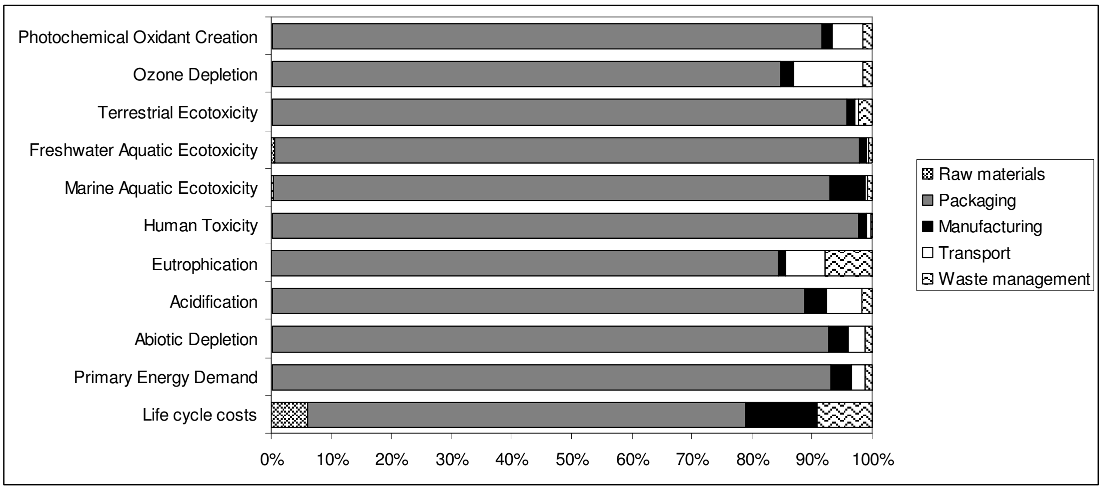

Figure 7-17 Contribution of different life cycle stages to environmental and economic impacts for the 0.5 l PET bottle

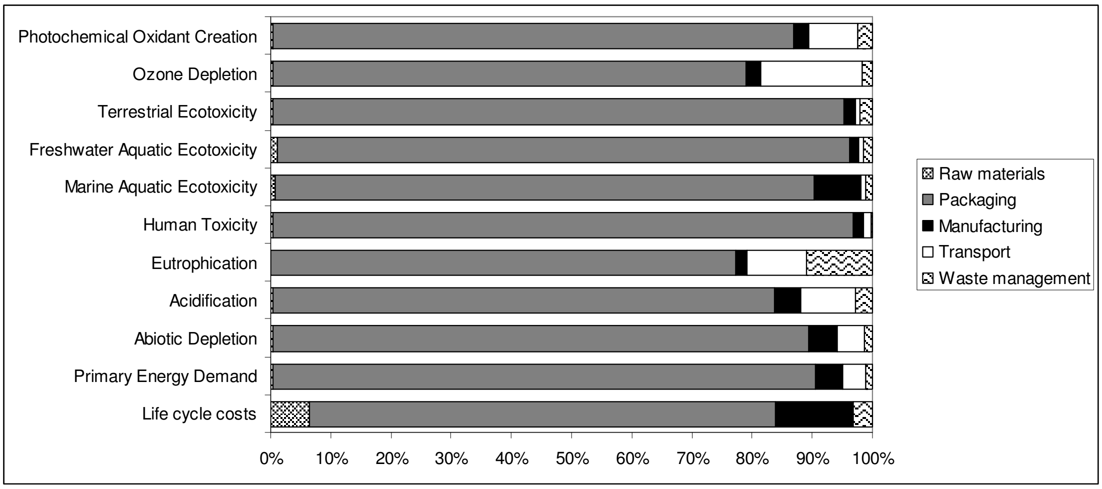

Figure 7-18 Contribution of different life cycle stages to environmental and economic impacts for the 2 l PET bottle

7.4 Summary

The environmental and economic impacts in the life cycle of bottled water have been quantified using the LCA, LCC and VA analyses. The objectives of the case study have been met in that:

- the environmental and economic impacts in the life cycle of bottled water have been estimated considering three packaging options used in the UK: 0.75 l glass bottles, 0.5 l and 2 l PET bottles;
- the hot spots in the life cycle have been identified for the different types of packaging; and

- the life cycle environmental and economic impacts from the bottled water sub-sector have been estimated based on the findings of the LCA, LCC, VA and a UK market analysis.

The LCA results indicate that water packaged in the 2 l PET bottle has the lowest impacts for all the environmental impact categories including global warming. The glass bottle, on the other hand, is the least preferred option for all the environmental impacts. The results also show that packaging is the major hot spot for the environmental impacts, contributing between 88% (2 l PET bottle) and 93% (glass bottle) to all the environmental impacts.

A sensitivity analysis to assess the impact of refrigerated storage at retail shows that refrigeration increases the global warming potential of water packaged in the glass and 0.5 l PET bottles by about 2.3 and 2 times, respectively. The analysis takes into account the impacts of electricity consumption and leakage of refrigerants, and assumes a storage time of 24 hours.

Results of the sectoral analysis show that production and consumption of bottled water in the UK was responsible for over 300,000 tonnes of CO_2 eq. emissions in 2010. The results also show that marine aquatic ecotoxicity and ozone depletion potentials from glass bottles are disproportionately higher than their market share would suggest due to high atmospheric emissions of hydrogen fluoride and volatile organic compounds, respectively.

The results of the LCC indicate that water packaged in the glass bottle has the highest LCC (£60 per 1,000 l), whereas the LCC for the 0.5 l and 2 l PET bottles are similar (£30 per 1,000 l). However, when disposal of post-consumer packaging waste is taken into account, the LCC for the 2 l PET bottle is marginally lower than that of the 0.5 l PET bottle. Packaging is the major hot spot for the LCC, contributing between 80% (0.5 l and 2 l PET bottles) – 90% (glass bottle), mainly due to bottle production.

Based on the LCC results, value added for water packaged in the glass, 0.5 l PET and 2 l PET bottles have been estimated as £1,226, £640 and £390, respectively. Value added for the bottled water sector in the UK has been estimated as £1.2 billion in

2010, amounting to 0.1% of the UK GDP. An analysis of the contributions of the different life cycle stages to the life cycle impacts shows that packaging is the major contributor to environmental and economic impacts in the life cycle of bottled water.

A similar analysis has been carried out to assess the life cycle impacts of Scotch whisky, the findings of which are presented in the next chapter.

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8 LIFE CYCLE ASSESSMENT OF ENVIRONMENTAL AND ECONOMIC SUSTAINABILITY OF SCOTCH WHISKY

In the current chapter, the life cycle assessment of environmental and economic sustainability of Scotch whisky is presented. The environmental impacts are quantified using life cycle assessment (LCA) while life cycle costing (LCC) and value added (VA) assessments are used to quantify the economic aspects. A similar analysis is carried out for the Scotch whisky sector based on the results of the LCA, LCC and VA analyses. The LCA results are presented first, followed by the results of the LCC and VA analyses.

8.1 Life Cycle Assessment

This study follows the LCA methodology as specified in the ISO 14040/44 standards (ISO, 2006a&b), starting with definition of the goal and scope, and followed by inventory, impact assessment and interpretation of the results. Various sensitivity analyses are also performed.

8.1.1 Goal and scope of the LCA

The current LCA case study has four main goals:

i. to estimate the environmental impacts and identify the hot spots in the life cycle of Scotch whisky;
ii. to estimate how the impacts may be affected by the type of different packaging used in the UK: clear glass bottles (0.70 l) and green glass bottles (0.70 l);
iii. to estimate the life cycle impacts from the whole Scotch whisky sub-sector based on the findings from the first goal of the case study and a UK market analysis; and
iv. to estimate the effect of potential improvement options in the life cycle of Scotch whisky.

For the first goal of the study, the functional unit is based on 1,000 litres of Scotch whisky. For the sectoral analysis, the functional unit considers the total annual production and consumption of Scotch whisky in the UK. The life cycle of whisky is shown in Figure 8-1. The system boundary of the study is from 'cradle to grave', comprising the following life cycle stages:

- ***Raw materials***: all material and energy inputs for production of cereals (barley, maize and wheat);
- ***Packaging***: production of primary packaging materials – glass bottles, aluminium alloy closures and kraft paper labels;
- ***Manufacturing and filling***: production of electricity, steam and auxiliary materials for manufacturing of whisky;
- ***Transport***: transport of raw materials, packaging, grain spirit, packaged whisky and post-consumer waste packaging; and
- ***Waste management***: wastewater treatment of effluents from the distillery and disposal post-consumer waste packaging.

The following activities are excluded from the system boundary due to lack of data:

- production of secondary packaging materials;
- electricity consumption at the retail stage (whisky is normally stored at ambient temperature); and
- transport of consumers to purchase the drink and any storage at consumer.

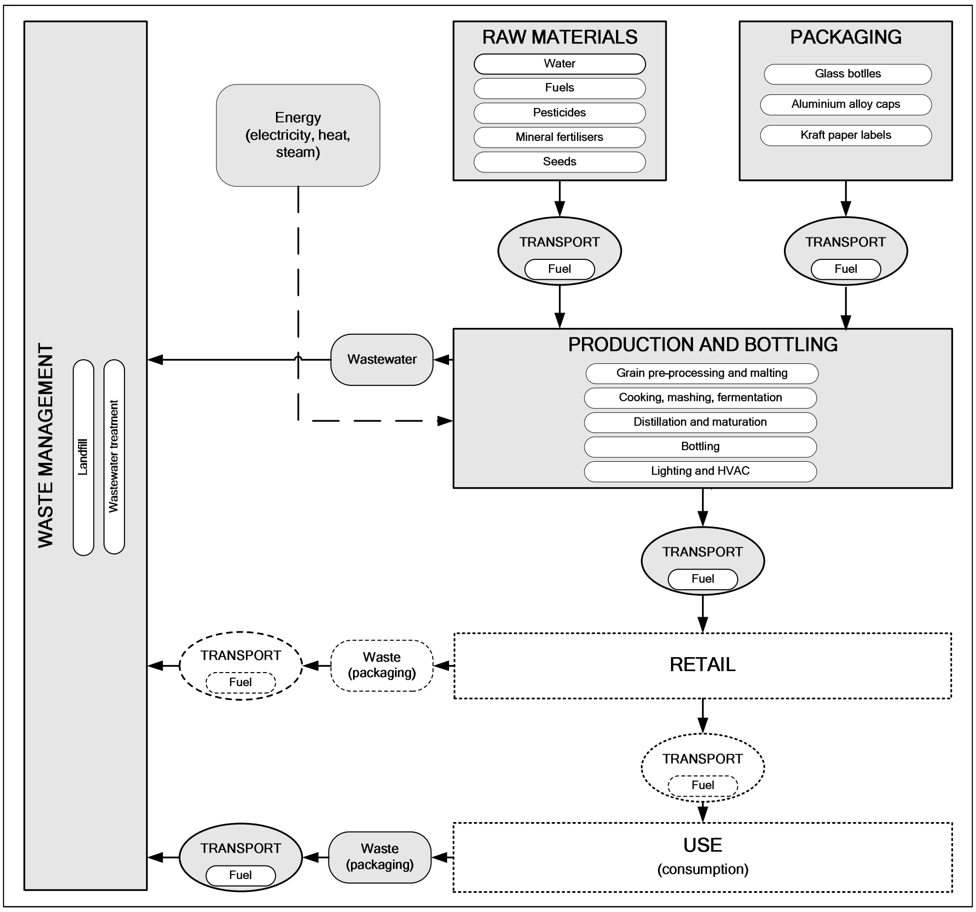

Figure 8-1 The life cycle of Scotch whisky

8.1.2 Inventory data and assumptions

Primary production data have been obtained from a life cycle-based optimisation study of the potable spirits industry (Bell, 2001) and represent company-specific data for the Scotch whisky supply chain. This includes the amounts and origin of the raw materials, electricity, steam and auxiliary materials for manufacturing of whisky as well as transport modes and distances in the life cycle of Scotch whisky. All other data have been sourced from the CCaLC (2011), Ecoinvent (2010) and Gabi (PE, 2010) databases. More detail on the inventory data and their sources is provided below.

8.1.2.1 Raw materials

As shown in Table 8-1, the major raw materials for manufacturing of whisky consist of barley, maize and wheat grains. Maize and wheat, the main raw materials for manufacturing of whisky, are delivered to the distillery on the Northern outskirts of

Glasgow, Scotland. Maize is sourced from France while wheat is sourced domestically from the UK. Barley, sourced from Denmark (Bell, 2001), is the main raw material for production of malt. Malt is essential for the distillation process as it provides the enzymes necessary for converting starch into fermentable sugars (Bell, 2001). The materials and energy required for the cultivation of barley, maize and wheat have been obtained from the Ecoinvent (2010) and Gabi (PE, 2010) databases. This includes fertilisers, pesticides, fuels and water.

Table 8-1 Raw materials for production of Scotch whisky

Raw material	Weight (kg/1000 l)	Source of LCI data
Barley grains	217	Ecoinvent (2010)
Maize grains	68	Gabi (PE, 2010)
Wheat grains	2340	Gabi (PE, 2010)

8.1.2.2 Packaging

The types of primary packaging materials are summarised in Table 8-1. The types of packaging selected for the study – clear and green glass bottles – are typically used for Scotch whisky. The clear and green glass bottles are assumed to contain 35% and 85% recycled content, respectively, based on the UK situation for clear and green container glass (British Glass, 2007). The tops are assumed to be made from 84% aluminium and 16% LDPE while the labels are made from kraft paper.

Table 8-2 Components and weights of the primary packaging materials

Packaging type	Weight (kg /1000 l)	Source of LCI data
Bottle body (0.70 l) (35% recycled clear glass) Bottle body (0.70 l) (85% recycled green glass)	734 734	CCaLC (2011) CCaLC (2011)
Closure (84% aluminium alloy, 16% LDPE)	5.3	Ecoinvent (2010)
Label (kraft paper)	1.4	Ecoinvent (2010)

8.1.2.3 Manufacturing

The main process stages involved in manufacturing of Scotch whisky are summarised below (Bell, 2001). The process begins with cooking of the cereal grains at high temperature and pressure in order to extract starch from the cereals. The starch is then converted to fermentable sugars in a process known as mashing. In this process, the cooked grain is infused with hot water and starch hydrolysis enzymes (provided by adding a small amount of dried malt – 10% of total cereal grain). The resulting sugary mash liquor is then fermented with yeast to produce liquor of about 7% v/v alcohol content. The liquor obtained from fermentation (including grains and yeast solids) is distilled in continuously operating distillation columns to produce a grain spirit of about 94% v/v ethanol. The grain spirit is reduced with water, filled into oak casks and transported to maturation warehouses, where it is matured for a minimum of three years. After maturation, the casked Scotch grain whisky is bottled for retail and consumption.

The manufacturing system is divided into seven subsystems – malting plant, grain distillery, maturation warehouse, carbon dioxide plant, combined heat and power (CHP) plant, dark grains plant and boiler plant. The manufacturing system yields five product outputs (exported functions) in addition to the whisky product – dark grains, pot ale, liquid carbon dioxide, fusel oil and electricity – which are sold and utilised in other applications. Dark grains and pot ale are used for animal feed (and feed supplements), liquid carbon dioxide is used in a range of applications including carbonation of beverages, fusel oil is used for perfume production and the excess electricity generated by the CHP plant is sold to the national electricity grid. It is therefore necessary that the environmental impacts are allocated among the co-products. Allocation of impacts has been carried out following the ISO 14040/44 guidelines (ISO, 2006). As part of the sensitivity analysis, the global warming potential (GWP) is estimated for different approaches to allocation based on the ISO 14040/44 guidelines.

The electricity and materials for manufacturing of Scotch whisky are summarised in Table 8-3. This takes into account the electrical energy, steam and auxiliary materials for all the subsystems.

Table 8-3 Electricity and materials for manufacturing of whisky

Material/energy	Quantity (per 1,000 l)	Source of LCI data
Electricity	983 MJ	Ecoinvent (2010)

Water	129,12 l	Ecoinvent (2010)
Steam (from natural gas)	2,888 kg	Gabi (PE, 2010)
Caustic solution	3.8 kg	Gabi (PE, 2010)
Fuel (methane)	210 kg	Gabi (PE, 2010)
Lubricants	0.2 kg	Gabi (PE, 2010)

8.1.2.4 Transport

The modes and distances for the whisky system are listed in Table 8-4. Transport distances for the raw materials have been estimated based on their respective sources. Where no specific data have been provided, a generic distance of 100 km has been assumed.

Table 8-4 Transport modes and distances in the whisky supply chain

Material	Transport mode	Estimated distance (km)	Source of LCI data
Barley grains	Ship	320	ILCD (2010), Gabi (PE, 2010)
Maize grains	Truck (40 t)	500	Gabi (PE, 2010)
Wheat grains	Truck (40 t)	200	Gabi (PE, 2010)
Grain spirit (to spirit store)	Truck (40 t)	30	Gabi (PE, 2010)
Packaging (bottles, closures and labels)	Truck (40 t)	100	Gabi (PE, 2010)
Whisky product (to retail)	Truck (40 t)	100	Gabi (PE, 2010)

8.1.2.5 Waste management

As indicated in Table 8-5, all the relevant waste streams have been considered, including in-process solid waste and effluents from the distillery, as well as post-consumer waste packaging. The in-process waste streams, consisting of grain chaff from pre processing of cereal grains and the malt system, are sent to landfill. Effluents from the distillery, consisting of wastewater from cooking of grains as well as the carbon dioxide, dark grains and boiler plants, are sent to wastewater treatment. The average UK waste management options have been assumed for the post-consumer waste packaging (see Table 8-5).

Table 8-5 Waste materials and management options

Waste	Amount (kg/1000 l)	Waste management option	Source of data for waste management option	Source of LCI data
Glass bottles (clear glass; 35% recycled content)	477.1	65% landfilled	British Glass (2009)	ILCD (2010), Gabi (PE, 2010)
Glass bottles (green glass; 85% recycled content)	110.1	15% landfilled	British Glass (2009)	ILCD (2010), Gabi (PE, 2010)
Closures (84% aluminium alloy, 16% LDPE)	5.3	Landfilled	Assumed	Gabi (PE, 2010)
Kraft paper label	1.4	Landfilled	Assumed	Gabi (PE, 2010)
Chaff from pre-processing of cereal grains	9.4	Landfilled	Manufacturer	Gabi (PE, 2010)
Effluents from the distillery	24,787	Wastewater treatment	Manufacturer	Gabi (PE, 2010)

8.1.2.6 Allocation of environmental impacts

As mentioned previously, the manufacturing system yields five product outputs (in addition to the whisky product) – dark grains, pot ale, liquid carbon dioxide, fusel oil and electricity (Table 8-6).

Table 8-6 Co-products from whisky manufacturing[a]

Co-product	Quantity (per 1000 l)	Use
Dark grains	737.6 kg	Animal feed
Pot ale	83.8 kg	Animal feed
Fusel oil	2.0 kg	Perfume production
Liquid carbon dioxide	436.5 kg	Beverage carbonation
Electricity	734.6 MJ	Exported to grid

[a]All LCI data from the Ecoinvent (2010) database

In order to account for impacts from Scotch whisky production, the environmental impacts have been allocated among the co-products. The allocation has been carried out according to the ISO 14040 guidelines (ISO, 2006) using the 'avoided burden' approach. This involves subtracting the impacts of producing these co-products in a conventional/alternative way from the total impacts arising from the whisky system. Life cycle inventory (LCI) data for the production of these co-products in a conventional/alternative way have been obtained from the Ecoinvent (2010) database. To examine the influence on the results of the allocation method, allocation by economic value has also been carried out for GWP. This is described further below.

8.1.2.7 Data quality

Using the data quality assessment approach presented in Chapter 3 of this work, the LCA data quality has been assessed for the Scotch whisky system. The overall LCA data quality for the Scotch whisky system has been estimated as 'Medium'. More detail on the LCA data quality assessment for the Scotch whisky system is provided in Appendix A3.5.

8.1.3 Impact assessment and interpretation

The Gabi 4.3 LCA software has been used to model the system. The CML 2001 (Guinee et al., 2001) impacts characterisation method has been used to estimate the environmental impacts. In addition to the impacts included in the CML method, two further aspects are considered: primary energy demand and water demand. The global warming potential (GWP) is discussed first, followed by the other environmental impacts.

8.1.3.1 Global warming potential (GWP)

The results for the GWP are shown in Figure 8-2 and Figure 8-3. The 'avoided burden' refers to the impact allocated to the five co-products (dark grains, pot ale, liquid carbon dioxide, fusel oil and electricity). Figure 8-2 shows the results of the GWP when different approaches for allocation in LCA are used. The four approaches for allocation of the impacts among the co-products are explained below:

- AB 1: allocation by avoided burden for electricity, fusel oil, carbon dioxide and pot ale syrup; no allocation by economic value;
- AB 2: allocation by avoided burden for electricity, fusel oil and carbon dioxide; allocation by economic value used for the other co-products;
- AB 3: allocation by avoided burden for electricity; allocation by economic value used for the other co-products; and

- AB 4: allocation by economic value for all the co-products.

As can be seen in Figure 8-3, whisky packaged in clear glass bottles has a higher GWP than the product packaged in green glass bottles. This is mainly due to the fact that the former has a lower content (35%) of recycled glass cullet than the latter (85%), thus requiring greater amounts of virgin glass and energy for bottle manufacturing, as well as generating greater amount of post-consumer waste packaging.

The manufacturing stage is the major hot spot for GWP in the whisky system, accounting for 49% of the total (minus avoided burden). This is mainly due to carbon dioxide emissions from production of energy (electricity and heat). Non-methane volatile organic compounds (NMVOC), arising from losses during the maturation process, also contribute to the impacts from the manufacturing stage.

The GWP contribution from raw materials (22%) is mainly due to nitrous oxide and carbon dioxide emissions from cultivation of wheat while The GWP contribution from packaging (15%) is mainly due to carbon dioxide emissions from manufacturing of glass bottles.

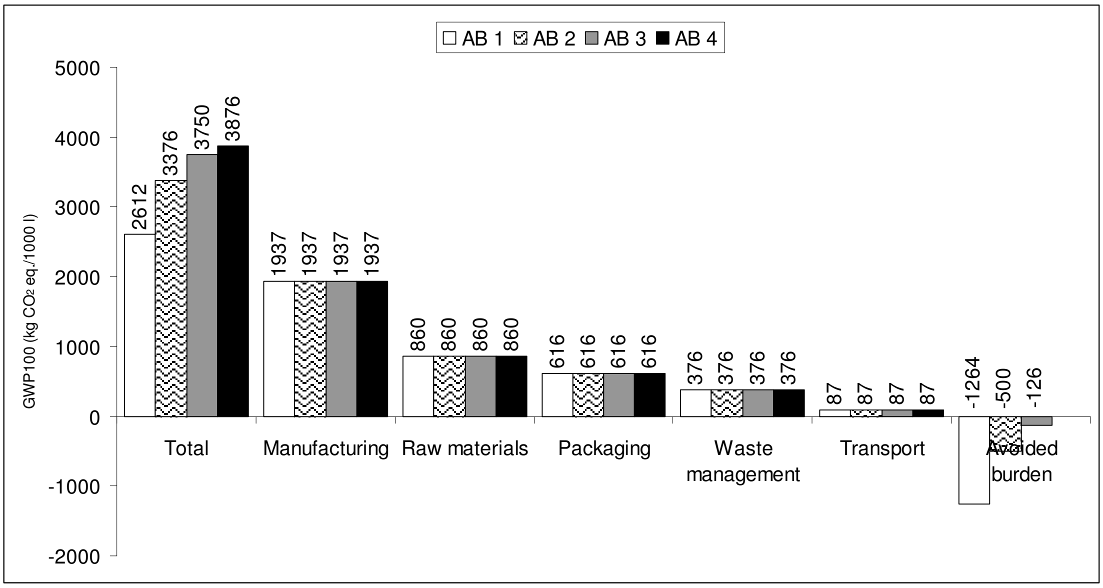

Figure 8-2 Global warming potential of Scotch whisky showing results for different allocation methods
[Clear glass, 35% recycled content]

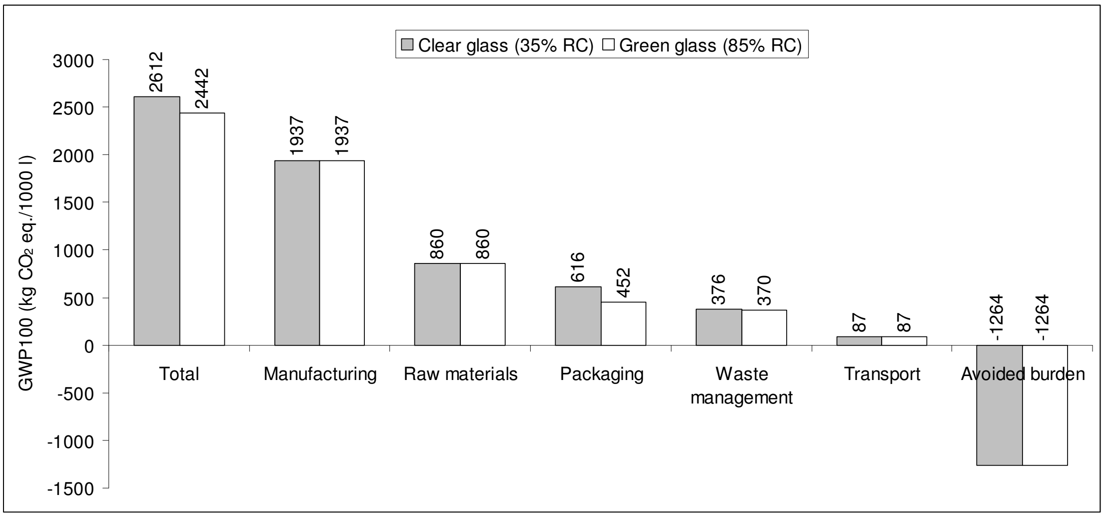

Figure 8-3 Global warming potential of Scotch whisky for different types of packaging also showing the contribution of different life cycle stages
[Allocation of impacts by the avoided burden approach]

8.1.3.2 Other environmental impacts

The 'avoided burden' approach has also been used for allocation of the other environmental impacts. As shown in Figure 8-4, the product packaged in green glass bottles has a lower impact for ten out of eleven impacts: primary energy demand (PED), abiotic depletion (ADP), acidification (AP), eutrophication (EP), human toxicity (HTP), marine, freshwater and terrestrial ecotoxicity (MAETP, FAETP and TETP), ozone depletion (ODP) and photochemical oxidant creation (POCP) potentials. Water demand (WD), on the other hand, is similar for the two packaging systems.

The contributions of the different life cycle stages to the environmental impacts are illustrated in Figure 8-5. Production of raw materials is the major contributor to four out of eleven impact categories: PED, AP, EP and TETP. Cultivation of wheat is mainly responsible for the PED, accounting for 46% of the total. Atmospheric emissions of ammonia (28%) and waterborne nitrate emissions (30%) from wheat cultivation are mainly responsible for the raw material contribution to AP and EP, respectively. Emissions of chromium to soil from cultivation of maize (15%) and barley (12%) are mainly responsible for TETP from production of raw materials.
Production of packaging is the main life cycle stage regarding HTP, MAETP, FAETP and ODP. HTP from packaging is mainly due to airborne emissions of selenium

(29%) from production of glass bottles. Waterborne emissions of copper, nickel and vanadium are mainly responsible for FAETP from packaging (28%), while MAETP is mainly due to atmospheric emissions of hydrogen fluoride (80%) from production of glass bottles. On the other hand, ODP from packaging is mainly as a result of atmospheric emissions of non methane volatile organic compounds (NMVOC) from production of glass bottles. An interesting point to note is that HTP and ODP are mainly caused by the co-products (liquid carbon dioxide and dark grains) hence the negative values obtained.

The manufacturing stage is the key life cycle stage regarding WD, ADP and POCP. The mashing and distillation processes, as well as the dark grains plant account for the bulk of water demand, accounting for 38%, 22% and 22% of the WD from manufacturing. ADP from manufacturing is mainly as a result of consumption of the primary energy resources (natural gas, crude oil and coal) for electricity and natural gas production. POCP from manufacturing is mainly due to direct emissions of NMVOCs to air from the maturation warehouses.

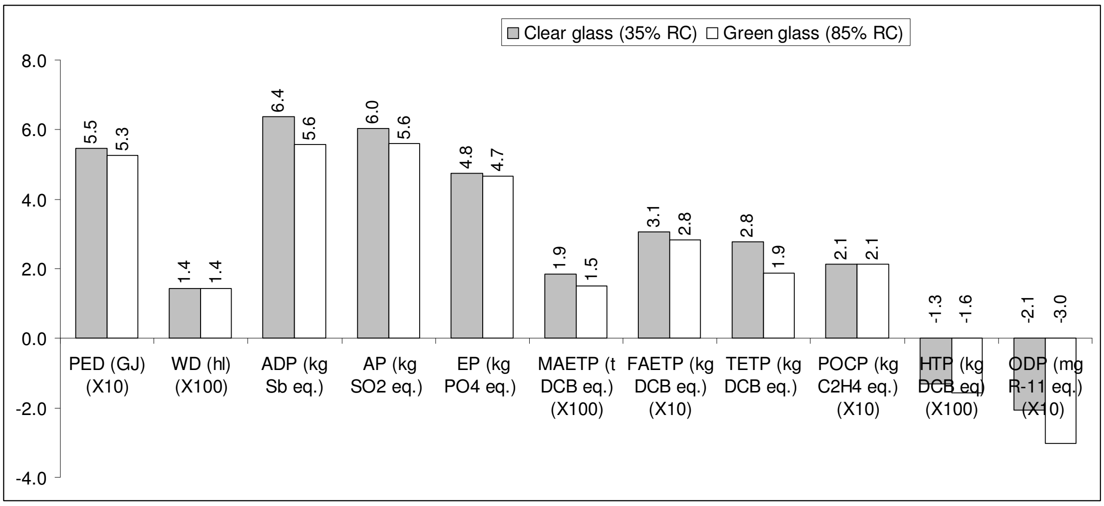

Figure 8-4 Environmental impacts in the life cycle of Scotch whisky
[*PED* primary energy demand, *WD* water demand, *ADP* abiotic depletion potential, *AP* acidification potential, *EP* eutrophication potential, *HTP* human toxicity potential, *MAETP* marine aquatic ecotoxicity potential, *FAETP* freshwater aquatic ecotoxicity potential, *TETP* terrestrial ecotoxicity potential, *ODP* ozone depletion potential, *POCP* photochemical ozone creation potential. The scaled values should be multiplied with the factor shown in brackets against the relevant impact to obtain the original values. Allocation of impacts by the avoided burden approach. The scaled

values should be multiplied with the factor shown in brackets against the relevant impact to obtain the original values.]

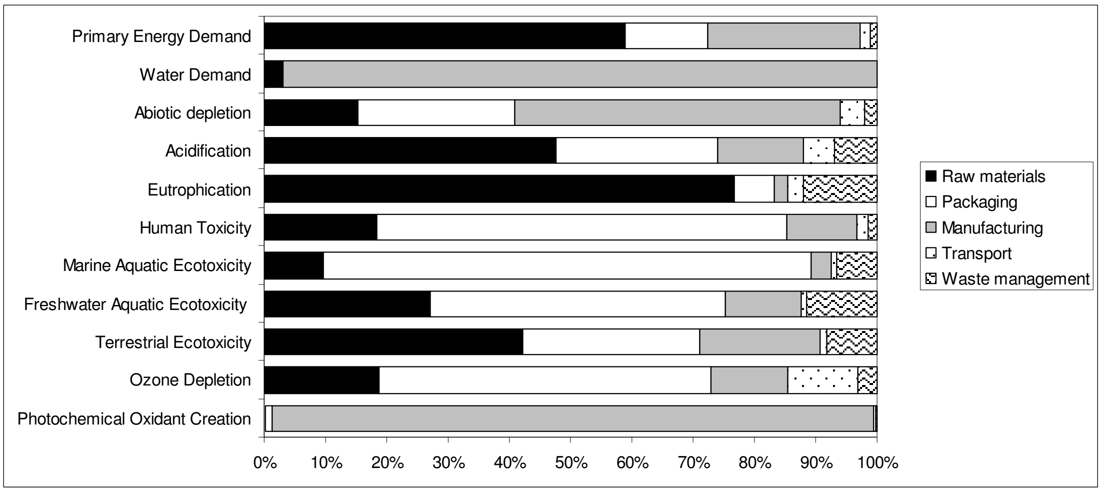

Figure 8-5 Contribution of different life cycle stages to the environmental impacts

8.1.3.3 Environmental impacts at the sectoral level

In order to estimate the life cycle environmental impacts from the Scotch whisky sector, the results of the current study have been extrapolated for the total production and consumption of 25.8 million litres of Scotch whisky in 2009 (Scotch Whisky Association, 2010). Of this amount, about 93% were packaged in clear and 7% in green glass bottles.

From Figure 8-6, it can be seen that production and consumption of whisky in the UK was responsible for over 74,000 tonnes of CO_2 eq. emissions in 2009. This represents about 0.6% of the GHG emissions from the whole food and drink sector[30]. Although the estimates for the GHG emissions are not directly comparable as in one case they represent the life cycle emissions (for whisky) and mainly direct emissions (food and drink sector), they are nevertheless an indication of the sector's contribution to the total UK GHG emissions.

[30] Estimated based on the stated contribution by FDF (2008) and Defra (2006) of the food and drink sector of 2% to total UK GHG emissions and the estimated UK GHG emissions of 582.4 million tonnes CO2 eq. (DECC, 2011).

Figure 8-7 shows the comparison of environmental impacts for different types of packaging relative to their market share. While it is difficult to put the other impacts in context, it can be observed that freshwater aquatic ecotoxicity for the green glass bottles is higher than its market share would suggest.

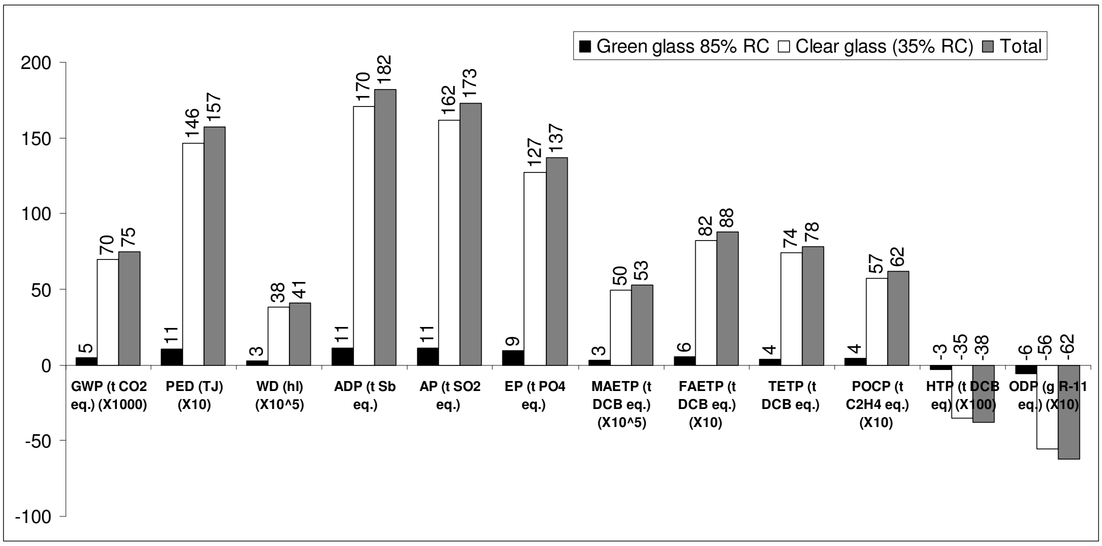

Figure 8-6 Life cycle environmental impacts of Scotch whisky in the UK
[Allocation of impacts by the avoided burden approach. The scaled values should be multiplied with the factor shown in brackets against the relevant impact to obtain the original values.]

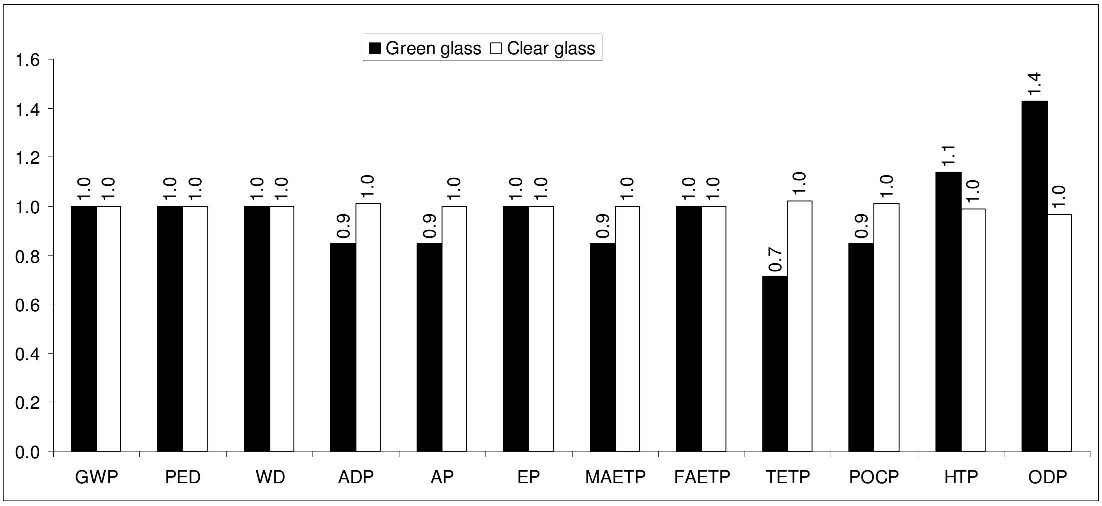

Figure 8-7 Comparison of environmental impacts for different types of packaging relative to their market share
[Allocation of impacts by the avoided burden approach. The values represent the ratio of the impact for each packaging type and its market share of 7% for green glass bottles and 93% for clear glass bottles.]

8.1.3.4 Impact of very high gravity brewing on the environmental impacts

Considering that the manufacturing stage is the key contributor to the GWP as well as other environmental impacts, it is necessary to assess the effect of options for reducing the impacts from this life cycle stage. The impact of introducing cleaner technologies such as very high gravity (VHG) brewing has been identified as a viable option to achieve environmental impact reduction from whisky manufacturing (Bell, 2000). This involves replacing the Coffey-still distillation apparatus in the distillery with a more conventional system in order to take advantage of very high gravity washes of up to 15% v/v alcohol content (Bell, 2000). The author observes that the introduction of VHG brewing reduces the steam requirement by around 40%. Applying this technological change to the manufacturing stage, the life cycle environmental impacts are shown in Figure 8-8.

It can be seen that, compared to the current operations, VHG brewing results in GWP savings of around 1% per functional unit. Environmental savings for the other impact categories range from 0.1% (MAETP, FAETP, HTP and POCP) to 11% (ADP). At the sectoral level, the GWP savings amounts to 749 tonnes CO_2 eq. annually.

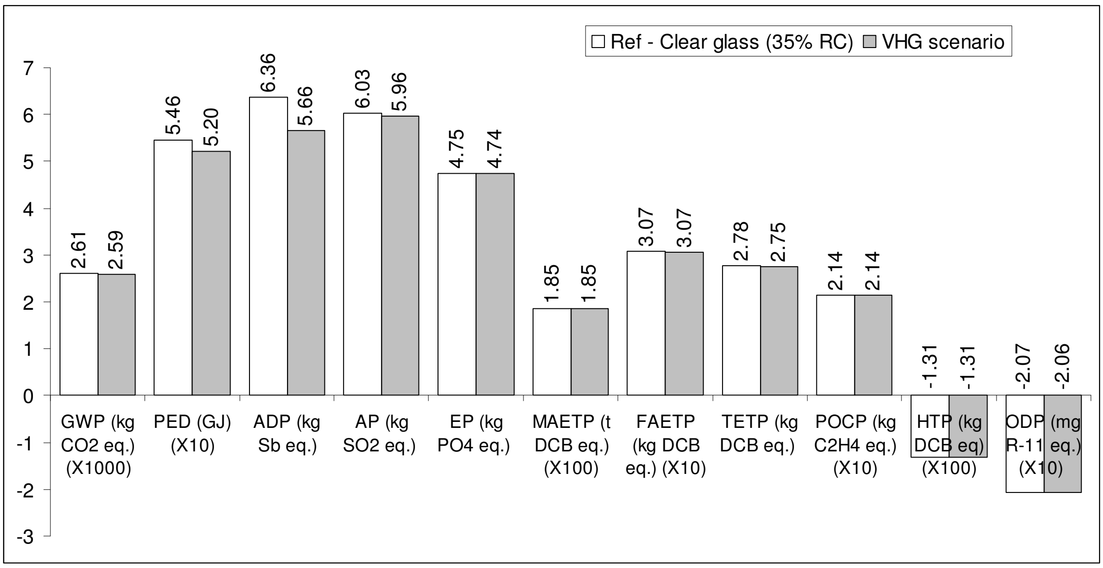

Figure 8-8 Impact of very high gravity brewing on the environmental impacts per 1000 litres of Scotch whisky

[Ref – reference case as considered in the study. Allocation of impacts by the avoided burden approach. The scaled values should be multiplied with the factor shown in brackets against the relevant impact to obtain the original values.]

8.1.3.5 Impact of recycled glass content on the environmental impacts

Given that packaging is an important contributor to the environmental impacts in the life cycle of Scotch whisky, the impact on the environmental impacts of recycled content of the bottles has been assessed. The results in Figure 8-9 show that increasing the recycled content of glass bottles by 10% results in GWP savings of 1.5% or 37 kg CO_2 eq. per functional unit. The savings in GWP arise from the packaging and waste management stages due to reduced energy for bottle manufacturing and reduced post-consumer waste sent to landfill. At the sectoral level, a 10% increase in the recycled content of the clear and green glass bottles results in GWP savings of around 12% or 8,803 tonnes of CO_2 eq. emissions annually. Environmental impact savings for the other impacts range from 0.4% (PED) to 2.3% (ODP).

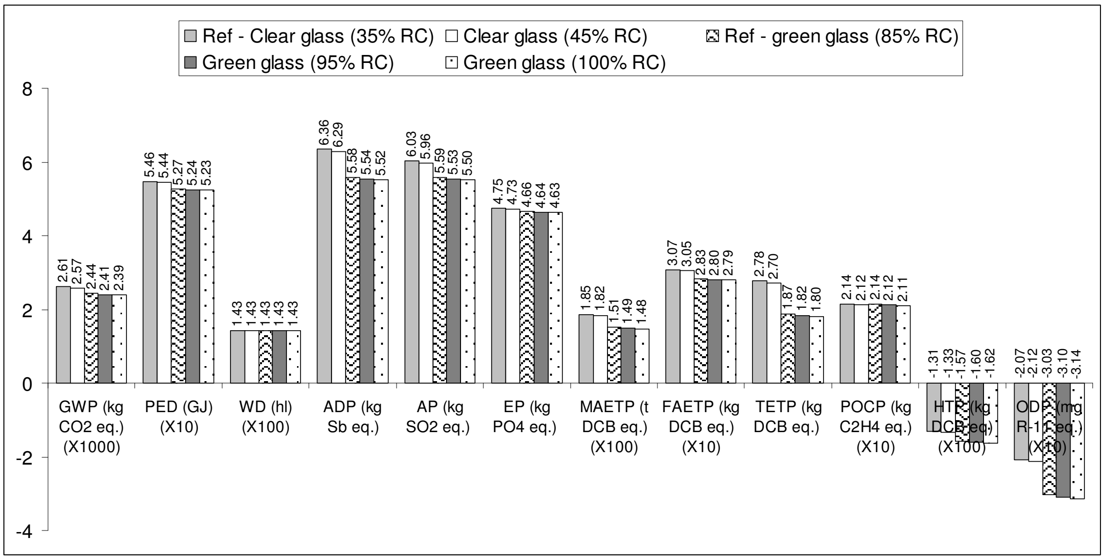

Figure 8-9 Impact of recycled content on the environmental impacts

[Ref – reference case as considered in the study. RC – recycled content. The scaled values should be multiplied with the factor shown in brackets against the relevant impact to obtain the original values.]

8.1.3.6 Impact of lightweighting on the environmental impacts

The effect of lightweighting on the environmental impacts, assessed as part of the sensitivity analysis, is shown in Figure 8-10. The results show that a 10% reduction in the weight of the bottles results in GWP savings of 6.2% or 151 kg CO_2 eq. per functional unit. The savings arise from reduced energy and material input for bottle manufacturing and reduced impact from transporting less glass. At the sectoral level, a 10% reduction in the weight of the clear and green glass bottles results in GWP savings of around 16% or 11,964 tonnes CO_2 eq. emissions annually Environmental impact savings for the other environmental impacts range from 0.1% (POCP) to 5.6% (MAETP).

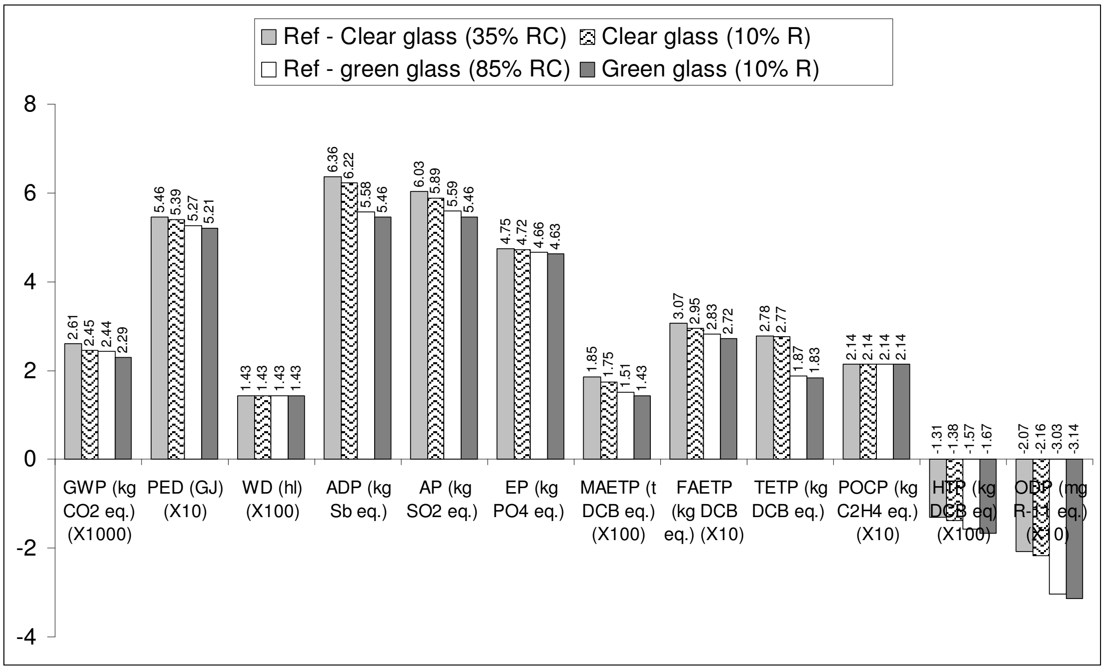

Figure 8-10 Impact of lightweighting on the environmental impacts
[Ref – reference case as considered in the study. R – reduction. The scaled values should be multiplied with the factor shown in brackets against the relevant impact to obtain the original values.]

8.1.3.7 Impact of organic wheat on the environmental impacts

Given that the raw materials stage is a key contributor to the environmental impacts mainly due to wheat production, the environmental impact of wheat production in different countries and alternative production systems (conventional and organic) has been investigated as part of the sensitivity analysis. As demonstrated by Figure 8-11, the environmental impacts of wheat produced in different countries and with different agricultural production systems can differ significantly. As can be seen, conventional wheat produced in Spain has a higher GWP than wheat produced in the other countries through conventional or organic means. Regarding the impacts of conventional and organic production systems, it can be seen that conventional wheat produced in Canada has a lower GWP than organic wheat produced in Switzerland despite the reliance of agri chemicals in conventional systems. In contrast, organic wheat produced in Switzerland has a lower GWP than conventional wheat produced in the same country. The study by Azapagic et al. (2011) identifies factors including differences in the land area used, soil types, climatic conditions and farming practices as reasons for differences in the impacts, and highlights the complexity associated with environmental impacts from farming.

The comparison between conventional and organic wheat for the full environmental impacts is based on wheat production in Switzerland due to data availability. As can be seen in Figure 8-12, organic wheat performs better than conventional wheat in 8 out of 11 impact categories (GWP, FAETP, HTP, MAETP, POCP, ODP, ADP and water consumption). Conventional wheat, on the other hand, performs better in 3 impact categories (AP, EP and TETP). Considering wheat production in isolation of the rest of the system, GWP or organic wheat is around 21% lower (per kg of wheat) than that of conventional wheat. At the systems level, organic wheat would reduce GWP by around 5% in the life cycle of Scotch whisky (see Figure 8-13). At the sectoral level, use of organic wheat has the potential to reduce the GWP by around 16,500 tonnes CO_2 eq. emissions annually.

Similarly, the studies by Williams et al. (2006) and the LCA Food Database (2007) found that the GWP from production of organic wheat is around 2% and 61% lower than that of conventional wheat respectively. For AP and EP, organic wheat increases the impacts by factors of 5 and 4 respectively per kg of wheat (see Figure 8-12). Similar to other agricultural commodities, results from different LCA studies will be sensitive to various factors including methodological choices, co-products, crop yields and region-specific factors. Therefore, these results have to be interpreted with care. Prior to making recommendations regarding sourcing of organic wheat, a more detailed assessment of the life cycle environmental impacts is required. In addition to understanding the complexity of environmental impacts from farming, economic and social aspects have to be understood to provide a more robust base for decision-making in this regard.

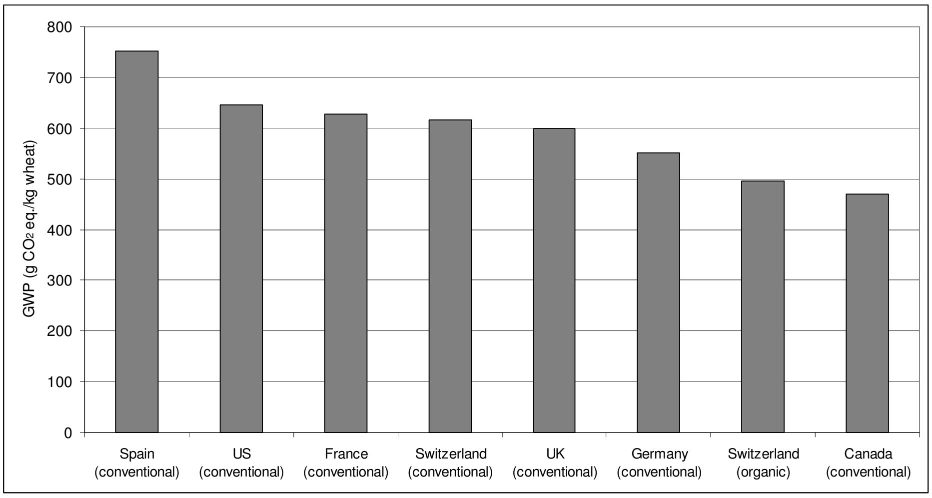

Figure 8-11 Global warming potential of wheat cultivated in different countries
[GWP for UK (conventional) and Canada (conventional) wheat based on data from Defra (2008) and Environment Canada (2008) cited in Azapagic et al. (2011). All other GWP data from the Ecoinvent (2010) database]

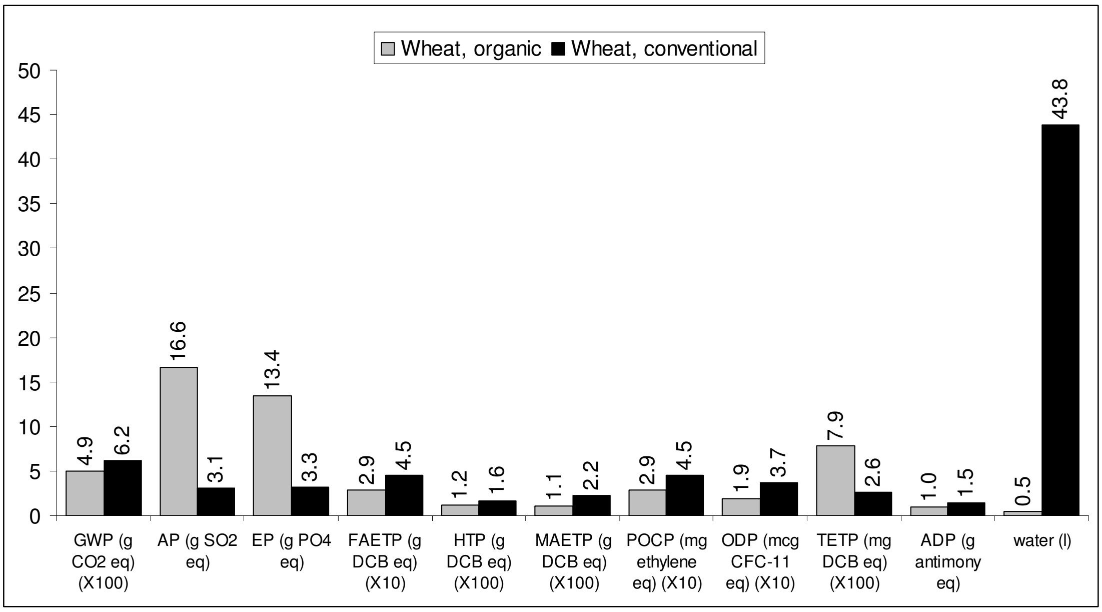

Figure 8-12 Impact of organic wheat on the environmental impacts per kg of wheat
[The scaled values should be multiplied with the factor shown in brackets against the relevant impact to obtain the original values. The life cycle impact assessment data represents conventional and organic wheat produced in Switzerland. Data from the Ecoinvent (2010) database]

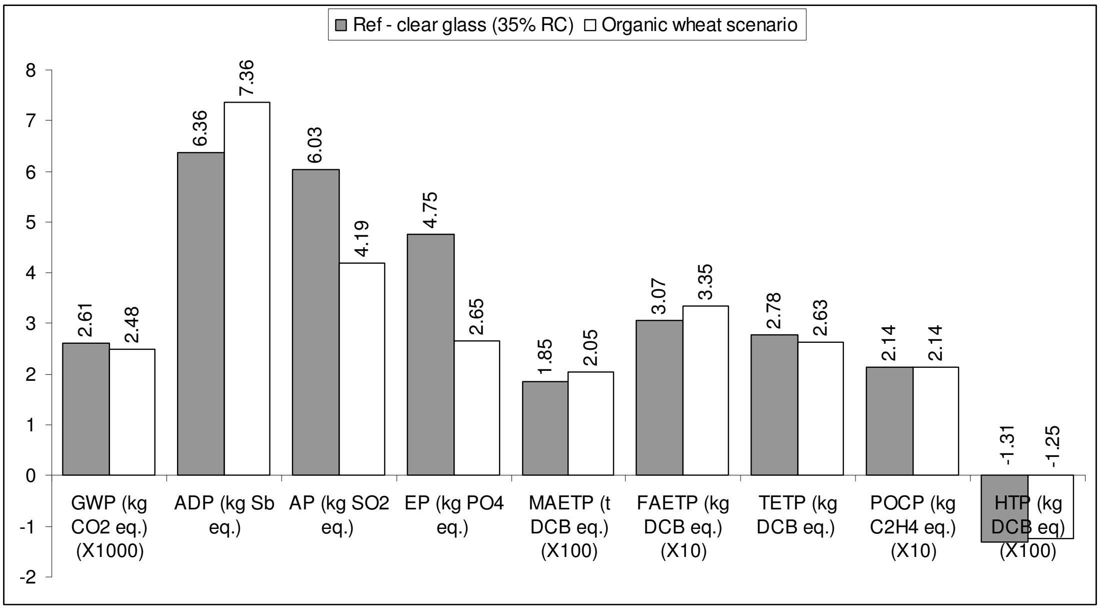

Figure 8-13 Impact of organic wheat on the environmental impacts per 1,000 litres of Scotch whisky

[Ref – reference case as considered in the study. The scaled values should be multiplied with the factor shown in brackets against the relevant impact to obtain the original values.]

8.2 Life cycle economic assessment

Two economic aspects are considered in the current study: life cycle costs and value added. Details of the LCC and VA methodologies followed in this work can be found in Chapter 3. The life cycle costs are considered from the perspective of the beverage producer, final consumers and the government.

8.2.1 Goal and scope

The current LCC case study has four main goals:

i. to estimated the life cycle costs and value added, and identify the hot spots in the life cycle of Scotch whisky consumed in the UK;
ii. to analyse how the impacts may be affected by the types of packaging used for Scotch whisky: clear glass bottles (0.70 l) and green glass bottles (0.70 l);
iii. to estimate the life cycle costs and value added from the Scotch whisky sub-sector based on the findings of the first two goal of the study and a UK market analysis; and
iv. to estimate the impact of improvement options on the life cycle economic impacts.

Similar to the LCA, the functional unit is based on 1,000 litres of Scotch whisky while the sub-sectoral analysis considers total annual production and consumption of Scotch whisky in the UK.

8.2.2 Inventory data and assumptions

The life cycle inventory data are based on the LCA data presented in section 8.1.2. Primary production cost data have been obtained from literature, including the costs of raw materials, electricity and auxiliary materials for manufacturing of whisky and waste management of in-process and post-consumer waste. It is assumed that freight costs are included in the costs of materials; therefore the cost impact for each material in the life cycle includes transport. It is also assumed that the producer bears the costs of the raw materials, packaging materials and waste management of in-process waste. The consumer, on the other hand, bears the cost of disposal of post-consumer waste packaging through taxes paid for waste disposal services. More detail on the cost data are provided below.

8.2.2.1 Raw materials

The raw material costs and sources in the life cycle of Scotch whisky are summarised in Table 8-7. In the absence of company specific data, the raw material costs have been sourced from international commodity markets. As cereals are largely traded on the international markets, this is arguably a reasonable approximation of actual costs.

Table 8-7 Raw materials for production of Scotch whisky

Raw material	Cost (£/1000 l)	Source of cost data
Barley grains	50.1	Europeangrain.com (2011)
Maize grains	11.7	Europeangrain.com (2011)
Wheat grains	367.4	ADVFN Plc. (2011)

8.2.2.2 Packaging

The costs of primary packaging materials are summarised in Table 8-8. It is important to note that the costs shown do not include fabrication of the final packaging (bottles, closures and labels). This is a limitation of the study but due to the lack of data (confidentiality), it was not possible to obtain these data.

Table 8-8 Primary packaging costs in the life cycle of Scotch whisky

Packaging type	Cost (£/1000 l)	Source of cost data
Clear glass bottle (0.70 l)		
Primary glass (65% content)[a]	243.3	Aliexpress.com (2011)
Recycled glass cullet (35% recycled content)[b]	2.2	WRAP (2011)
Green glass bottle (0.70 l)		
Primary glass (15% content)[c]	56.2	Aliexpress.com (2011)
Recycled glass cullet (85% recycled content)[b]	5.3	WRAP (2011)
Aluminium alloy (closure)[d]	7.2	LME (2011)
Kraft paper (label)[e]	0.6	FOEX indexes (2011)

[a]Price per kg of clear container glass.
[b]Average price per kg of recycled green glass cullet in the UK assumed.
[c]Price of green container glass in the international market.
[d]Price of primary aluminium in the international commodity market.
[e]Price of kraft paper in the international commodity market.

8.2.2.3 Manufacturing

The energy and material costs for production of Scotch whisky, as well as waste management of in-process waste are summarised in Table 8-9. The costs of wastewater treatment of effluents from the distillery and disposal of solid wastes have been included in the manufacturing stage as these costs are borne by the manufacturer.

Table 8-9 Electricity and materials for manufacturing of whisky

Material/energy	Cost (£/1000 l)	Source of cost data
Electricity	39.3	Electricityprices.org.uk (2011)
Water	34.2	United Utilities (2011)
Caustic solution	1.6	ICIS (2008)
Fuel (methane)	0.1	Indexmundi.com (2011)
Yeast	64.8	Alibaba.com (2011)
In-process waste		
Effluents from distillery (wastewater treatment)	99.6	Scottish Water (2011)
Solid waste (landfill)	12.6	WRAP (2011)

8.2.2.4 Waste management

The waste disposal costs for the post-consumer packaging waste are summarised in Table 8-10. The non-recycled content of the glass bottles, as well as the aluminium alloy closures and kraft paper labels are sent to landfill at the end of life.

Table 8-10 Electricity and materials for manufacturing of whisky[a]

Material	Cost (£/1000 l)
Clear glass (65% non-recycled content) Green glass (15% non-recycled content)	36.3 8.4
Aluminium alloy (closures)	0.4
Kraft paper (labels)	0.1

[a]All cost data from WRAP (2011)

8.2.2.5 Consumer costs

As observed earlier in section 8.2.2, it is assumed that the consumer bears the costs of disposal of post-consumer packaging waste through taxes paid for waste disposal services. These are shown as landfill costs in Table 8-10. The retail price of the product, which has been used to estimate VA, can also be classified as consumer costs.

8.2.2.6 Allocation of economic impacts

As mentioned earlier, the manufacturing system yields five product outputs (in addition to the whisky product): dark grains, pot ale, liquid carbon dioxide, fusel oil and electricity. Due to lack of data, fusel oil has not been included in the analysis. The costs of the co-products are summarised in Table 8-11. The impacts have been allocated among the co-products as described below.

The impacts arising from the generation of the co-products have been allocated by subtracting the costs of these co-products (Table 8-11) from the total life cycle costs arising from the whisky system. The principle is similar to the 'avoided burden' approach for allocation of environmental impacts.

Table 8-11 Co-products from whisky manufacturing

Co-product	Cost (£/1000 l)	Source of cost data
Dark grains	122.8	Scottish Agricultural College (2011)
Pot ale	7.6	Scottish Agricultural College (2011)
Liquid carbon dioxide	29.4	Confidential
Electricity	27.6	Electricityprices.org.uk (2011)

8.2.2.7 Data quality

Using the data quality assessment approach presented in Chapter 3, the LCC data quality has been assessed for the Scotch whisky supply chain. The overall LCC data quality has been estimated as ‘Medium’ for the different packaging systems (clear and green glass bottles) considered in the current study. More detail on the data quality assessment is provided in Appendix 4, section A4.5. It is important to note that the study assumes an equivalency between market prices and supply chain costs due to the lack of supply chain-specific data (confidentiality). However, the data quality analysis provides an indication of the level of confidence that can be placed in the results of this study.

8.2.3 Life cycle economic impacts and interpretation

The LCC is discussed first followed by the results of the VA analysis. Following this, the two economic aspects as discussed in relation to the Scotch whisky sub-sector, after which the impacts of improvement options are discussed.

8.2.3.1 Life cycle costing (LCC)

The results of the LCC are given in Figure 8-14. The LCC results shown represent the production costs of whisky accrued by the manufacturer, excluding the costs of disposal of post-consumer packaging waste which are borne by the consumer. However, post-consumer waste disposal costs are negligible, accounting for 5% and 2% of the total LCC for the clear and green glass bottles, respectively. It can be seen that whisky packaged in the clear glass bottle has a higher LCC (£747 per 1,000 l than whisky packaged in green glass bottles (£559 per functional unit). This is mainly due to the lower content of recycled glass cullet which influences the packaging costs. The estimates show that the LCC of Scotch whisky (£747/1,000 l) is similar to that of wine (£791/1000 l, see Chapter 6) despite the significantly higher energy use in the production of Scotch whisky. It can be observed from Figure 6-24 and Figure 8-14, that the LCC from the manufacturing stage in the Scotch whisky supply chain is significantly higher than that of wine due to the higher consumption of energy. However, when the ‘avoided costs’ or revenues from the co-products are taken into account, the total LCC for both supply chains are similar.

It can also be observed in Figure 8-14, that production of raw materials is the major hot spot regarding the LCC, contributing 57% and 77% of the total for the clear and green glass bottles, respectively. The LCC from raw materials is mainly (86%) due to wheat grains, while barley and maize account for 11% and 3%, respectively of the LCC from raw materials.

Manufacturing is also a key life cycle stage for the LCC, accounting for 34% and 45% of the LCC for the clear and green glass bottles, respectively. Electricity, water and auxiliary materials are responsible for 55% of the LCC from manufacturing while waste management of in-process waste (wastewater treatment of effluents and disposal of solid wastes) account for 45% of the LCC from manufacturing.

Packaging is a key stage for the clear glass bottles, contributing 34% of the total LCC, whereas it accounts for only 12% of the LCC for the green glass bottles. This is mainly due to the fact that the clear glass bottle requires about 4.3 times more primary (virgin) glass which, as the data indicates costs about 60 times more than recycled glass cullet.

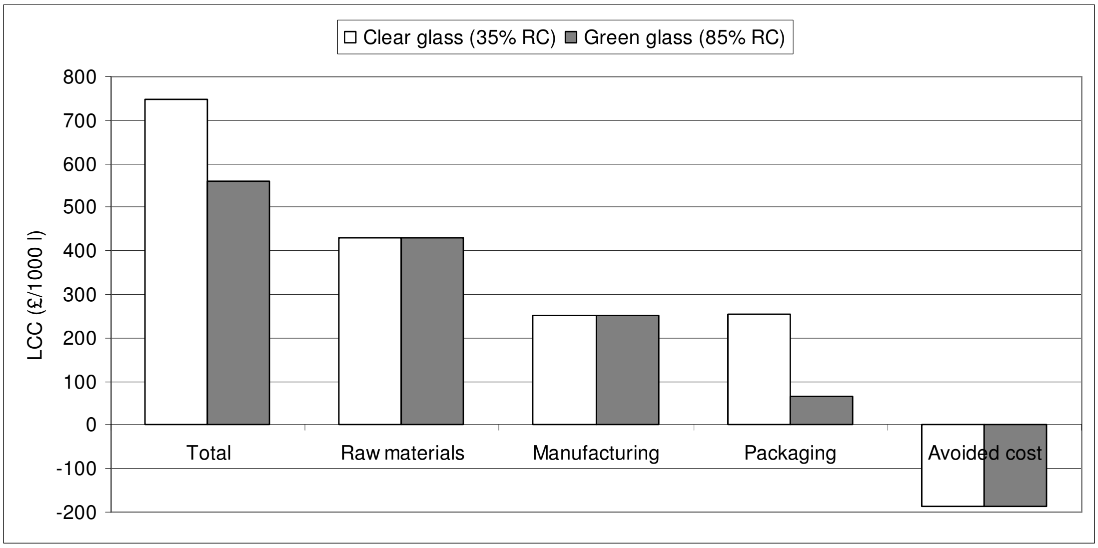

Figure 8-14 Life cycle costs of Scotch whisky for different types of packaging also showing the contribution from the different life cycle stages[31]

[31] The life cycle costs are shown from the manufacturer's perspective. However, costs for disposal of post-consumer packaging waste account for 5% and 2% of the LCC for Scotch whisky packaged in clear and green glass bottles, respectively.

8.2.3.2 Value added (VA)

The results for VA accrued by the manufacturer are shown in Figure 8-15. The VA represents the difference between the average retail price of Scotch whisky of £20,308 per 1,000 litres and its LCC. The retail price has been estimated based on the prices in the major retail outlets in the UK[32].

As can be seen in Figure 8-15, whisky packaged in the green glass bottle has a higher VA (£19,821 per 1,000 l) than that of the product packaged in the clear glass bottle (£19,633). This is mainly due to lower LCC for the green bottle as a result of higher input of recycled glass cullet, as mentioned earlier.

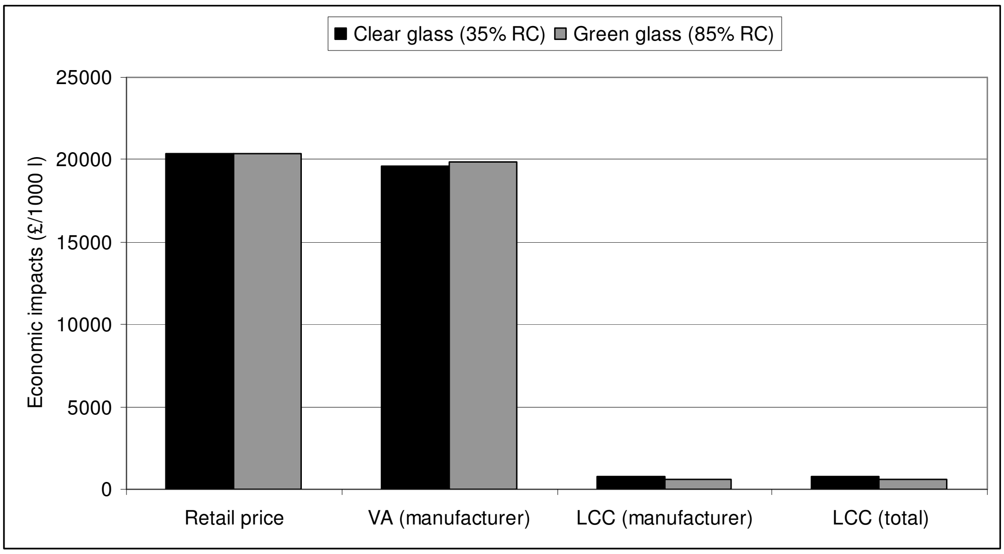

Figure 8-15 Value added for different types of packaging per 1000 litres of Scotch whisky also showing the retail price and life cycle costs
[VA (manufacturer) – value added accrued by the manufacturer. LCC (manufacturer) – life cycle costs for the manufacturer (minus costs for disposal of post-consumer packaging waste). LCC (total) – total life cycle costs including disposal of post-consumer packaging waste.]

8.2.3.3 Life cycle costs and value added at the sectoral level

Similar to the LCA, the LCC and VA from the Scotch whisky sub-sector have been estimated by extrapolating the results for the total production and consumption of

[32] Based on the average price of six medium range Scotch whiskies: Bells, Clan McGregor, J and B Rare, Johnnie Walker, Famous Grouse and William Grants in the major UK retail outlets: Asda, Tesco and Sainsbury's.

25.8 million litres of Scotch whisky in 2009[33] (Scotch Whisky Association, 2010). Considering the total consumption and the estimated market share by type of packaging (93% packaged in clear bottles and 7% packaged in green glass bottles), the LCC and VA for the Scotch whisky sub-sector are shown in Figure 8-16.

From Figure 8-16, it can be seen that that production and consumption of Scotch whisky in the UK was responsible for about £19.8 million in life cycle costs in 2009. Value added from the Scotch whisky sector for 2009 is estimated to be about £506.2 million, amounting to about 0.04% of the UK GDP for 2009[34].

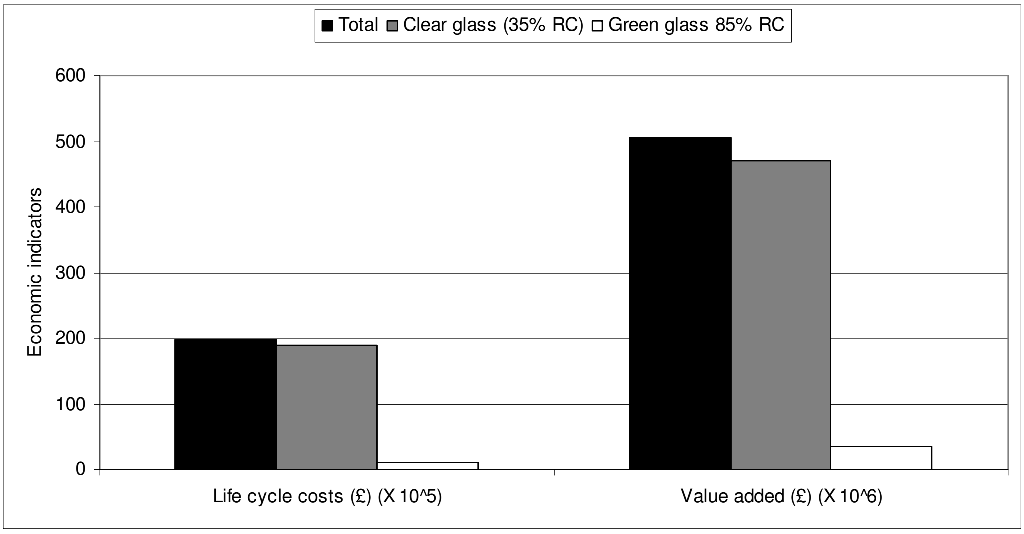

Figure 8-16 Economic impacts of Scotch whisky in the UK

8.2.3.4 Impact of recycled glass content on the economic impacts

As part of the sensitivity analysis, the impact on the LCC and VA of increasing the recycled content of the bottles has been assessed, as shown in Figure 8-17. The results indicate that, at the systems level, increasing the recycled content by 10% results in LCC savings and VA increase of around 6% and 0.2% for the manufacturer, respectively. At the sectoral level, a 10% increase in the recycled content of the clear and green glass bottles results in LCC savings and VA increase of around 5% or £1 million annually.

[33] Data from 2009 represent the most recent production and consumption data available at the time of this work.
[34] Based on the stated UK GDP of £1,392,634 million for 2009 (Key Note, 2011); sourced from Economic and Labour Market Review, November 2010, National Statistics website.

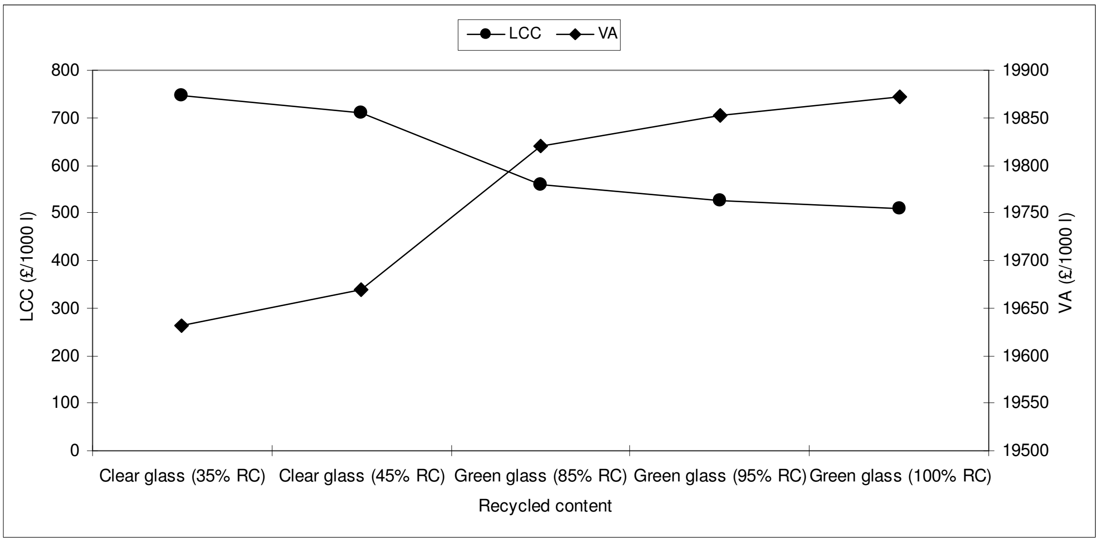

Figure 8-17 Impact of recycled content on the economic impacts in the life cycle of Scotch whisky

8.2.3.5 Impact of lightweighting on the economic impacts

The impact of lightweighting on the LCC and VA has also been assessed as part of the sensitivity analysis as shown in Figure 8-18. At the systems level, a 10% reduction in the bottle weight results in LCC savings and increased VA of around 0.5% and 0.02% for the manufacturer, respectively. At the sectoral level, a 10% reduction in the bottle weight for both clear and green glass bottles, results in LCC savings and increased revenue of around £1 million annually. Furthermore, a switch from clear glass bottles (35% recycled content) to 30% lighter green glass bottles (85% recycled content) would result in estimated cost savings and increased revenue of about 27% and 1%, respectively, amounting to £5.2 million.

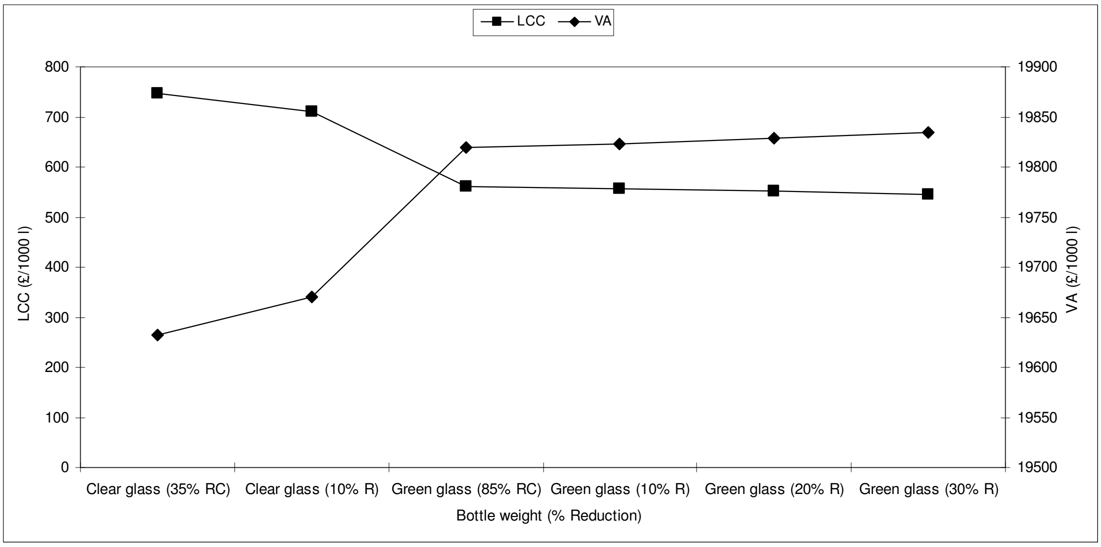

Figure 8-18 Impact of lightweighting on the economic impacts in the life cycle of Scotch whisky

8.3 Comparison of environmental and economic sustainability

As discussed in sections 8.1.3.1 and 8.1.3.2, the clear glass bottle is the least preferred packaging option regarding the environmental impacts. This is mainly due to the fact that the clear glass bottle has a lower content (35%) of recycled glass cullet than the green glass bottle (85%), thus requiring greater amounts of virgin glass and energy for bottle manufacturing, as well as generating greater amount of post-consumer packaging waste. The contributions of the different life cycle stages to the environmental impacts (from the LCA) and economic impacts (illustrated by the LCC) are shown in Figure 8-19. This enables the identification and comparison of the environmental and economic hot spots in the life cycle of Scotch whisky. It can be observed, from Figure 8-19, that the manufacturing, raw materials and packaging stages are the key hot spots for the environmental impacts, as well as the life cycle costs. Therefore, the raw materials and packaging stages have been the focus of performance improvement strategies, while it has not been possible to estimate the effect of performance improvements from manufacturing due to lack of data. Furthermore, Figure 8-20 and Figure 8-21 show the impact of increasing the recycled content and lightweighting of the glass bottles on the GWP and LCC in the life cycle of Scotch whisky. As can be observed in Figure 8-20 and Figure 8-21, increasing the recycled content and lightweighting of glass bottles result in both environmental and economic performance improvements in the life cycle of Scotch whisky.

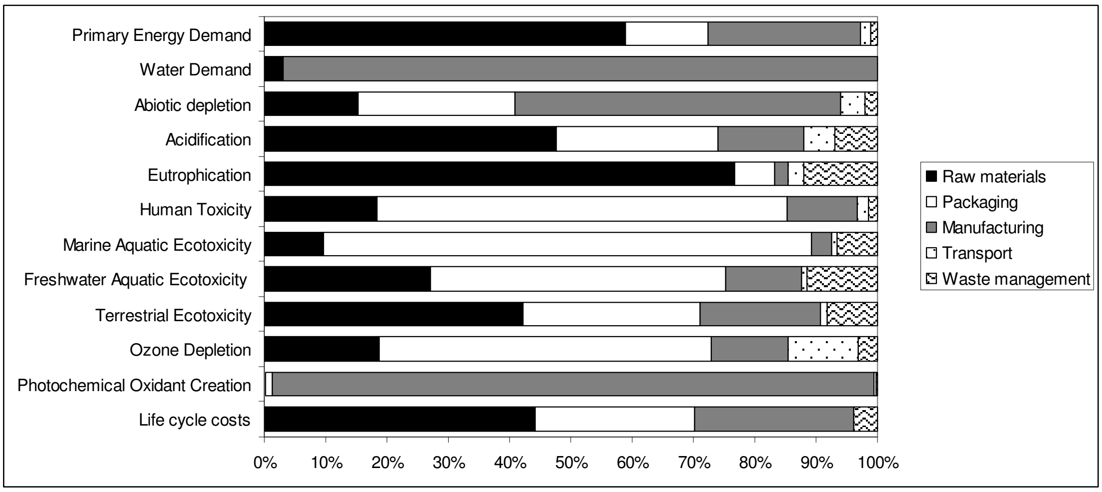

Figure 8-19 Contribution of different life cycle stages to the environmental and economic impacts

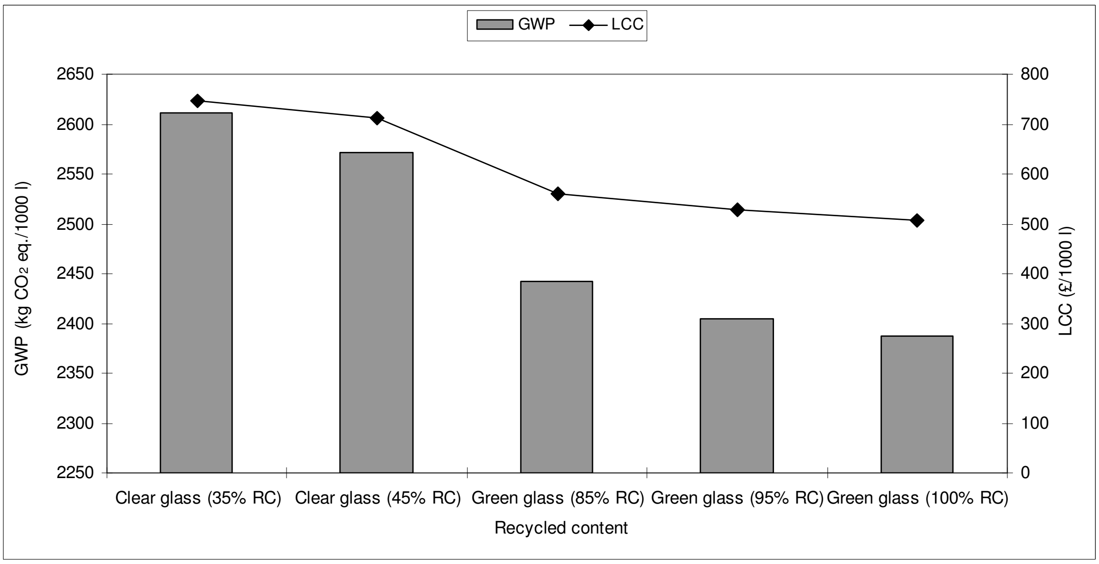

Figure 8-20 Impact of recycled content on the environmental and economic impacts per 1000 litres of Scotch whisky

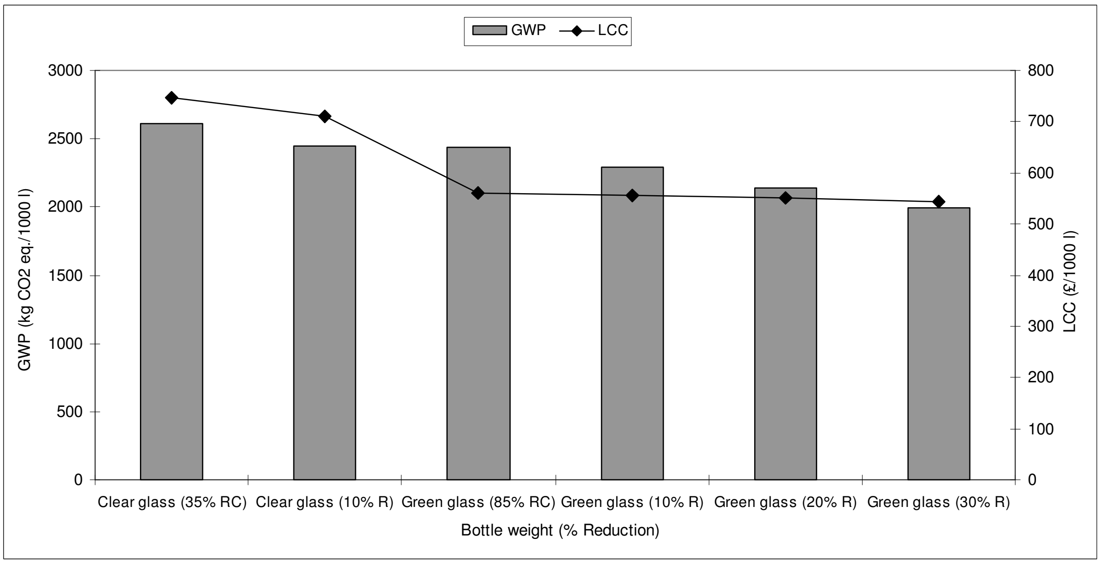

Figure 8-21 Impact of lightweighting on the environmental and economic impacts per 1000 litres of Scotch whisky

8.4 Summary

The environmental and economic impacts in the life cycle of Scotch whisky have been quantified using the LCA and LCC methodologies. The objectives of the case study have been met in that:

- the environmental and economic impacts in the life cycle of Scotch whisky have been estimated considering two packaging options used in the UK: clear glass and green glass bottles;
- the hot spots in the life cycle have been identified for the environmental and economic impacts;
- the life cycle environmental and economic impacts from the Scotch whisky sector have been estimated based on the findings from the LCA, LCC and a UK market analysis; and
- the effect of improvement options (recycled content and lightweighting) on the environmental and economic impacts have been estimated at the supply chain and sub-sectoral levels.

The results of the LCA indicate that whisky packaged in the green glass bottle is the preferred packaging option for all the environmental impacts considered except water demand, which is similar for the clear and green glass bottles. Manufacturing, packaging and raw materials are the key life cycle stages regarding the environmental impacts, accounting for 49%, 22% and 15%, respectively of the GWP. The sectoral analysis indicates that production and consumption of Scotch whisky in the UK was responsible for over 74,000 tonnes of CO_2 eq. emissions in 2009, representing about 0.6% of the GHG emissions from the whole food and drink sector.

Improvement options such as very high gravity brewing, increasing the recycled content and lightweighting of glass bottles are shown to reduce the environmental impacts in the life cycle of Scotch whisky. For example, 10% increase in the recycled content would reduce the global warming potential by 1.5% or 37 kg CO_2 eq. per 1,000 litres. At the sub-sectoral level, 10% increase in the recycled content for the clear and green glass bottles results in GWP savings of around 8,800 tonnes annually. Similarly, 10% reduction in the weight of the bottle results in global warming potential savings of about 6.2% or 151 kg CO_2 eq. per functional unit, with the potential for GWP savings of around 12,000 tonnes annually.

The LCC results indicate that whisky packaged in the green glass bottle has a lower LCC than that of the clear glass bottle due to the higher content of recycled glass cullet which influences the packaging costs. The raw materials stage is the major hot spot for the LCC, accounting for 57% and 77% of the total for the clear and green glass bottles, respectively, mainly due to wheat.

Manufacturing is also a key life cycle stage, accounting for 34% and 45% of the LCC for the clear and green glass bottles, respectively. Packaging is a key stage for the clear glass bottles, contributing 34% of the total LCC, whereas it accounts for only 12% of the LCC for the green glass bottles due to the fact that the clear glass bottle requires about 4.3 times more virgin glass which costs about 60 times more than recycled glass cullet.

Based on the results of the LCC, the value added for whisky packaged in clear and green glass bottles has been estimated as £19,633 and £19,821 per 1000 l, respectively. Value added from the Scotch whisky sector is estimated to be about £506.2 million, amounting to about 0.04% of the UK GDP for 2009.

The environmental improvement options are also shown to reduce LCC and increase VA for the manufacturer. For example, 10% increase in the recycled content of glass bottles would reduce the LCC by about 6% and increase VA by about 0.2%. Similarly, 10% reduction in the weight of glass bottles results in cost savings and increased revenue of 0.5% and 0.02%, respectively.

A comparison of the contributions of the different life cycle stages to the LCA and LCC results shows that raw materials, packaging and manufacturing are the key life cycle stages regarding the environmental and economic impacts in the life cycle of Scotch whisky. The results also demonstrate the decoupling of environmental and economic impacts from increasing the recycled content and lightweighting of glass bottles.

In the next chapter, an attempt is made to estimate the life cycle environmental and economic impacts from the whole beverage sector in the UK. A number of social issues arising from production and consumption of beverages in the UK are also highlighted.

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9 SUSTAINABILITY ASSESSMENT AT THE SECTORAL LEVEL

In the preceding chapters (4-8), the environmental and economic sustainability assessment of five sub-sectors of the UK beverage sector have been presented and discussed. Following the methodology outlined in Chapter 3, these results are used in the current chapter for a sustainability assessment of the UK beverage sector. It should be noted that the environmental and sustainability assessment at the sectoral level are only indicative as they only relate to the five types of drink addressed in this work. Nevertheless, this is the first time such as analysis has been attempted and these results can be used as a starting point for any future assessments of the whole sector. The social sustainability assessment provides a fuller picture at the sectoral level since most sustainability issues are also applicable to the drinks not considered in this work.

9.1 Environmental and economic sustainability

Figure 9-1 to Figure 9-3 show the combined results of the environmental and economic sustainability assessments for the five drinks considered in this work: carbonated soft drinks, beer (lager), wine (red), bottled water and Scotch whisky. The results in Figure 9-1 and Figure 9-2 correspond to the functional unit of 1,000 litres and indicate that bottled water packaged in the 2 l PET bottle has, on average, the lowest environmental impacts while Scotch whisky packaged in the 0.70 l clear glass bottle has the highest environmental impacts. Similar to the environmental impacts, bottled water packaged in PET bottles (0.5 and 2 l) has the lowest LCC while Scotch whisky has the highest LCC and VA.

The results in Figure 9-3 refer to the annual consumption of these drinks in the UK of around 10,704 million litres as follows:

- carbonated soft drink: 6,400 million litres per year (2010);
- beer: 2,084 million litres per year (2010)
- wine: 139 million litres (2010-2011)
- bottled water: 2,055 million litres (2010) ; and
- Scotch whisky: 25.8 million litres (2009).

These results are representative of around a half of the UK beverage sector by value. The contribution of the analysed sub-sectors to the total UK beverage sector by volume has not been determined due to lack of data[35]. As can be seen from Figure 9-3, in addition to the LCA, LCC and VA results discussed in the previous chapters, the consumption of abiotic resources such as glass, metals and plastics has also been calculated at the sectoral level.

Among the widely studied environmental issues, global warming has been identified as the environmental impact of primary interest for industry, the government and consumers in the UK as well as globally. As shown in Figure 9-3, estimates from the analysed sub-sectors reveal that consumption of the five beverages accounted for around 3.5 million tonnes of CO_2 eq. emissions in 2009/2010. This represents around 30% of the GHG emissions from the whole food and drink sector or around 0.6% of the total UK emissions in 2010 based on estimates from FDF (2008), Defra (2006) and DECC (2011). Although these estimates are not directly comparable as in one case they represent direct emissions (food and drink sector and total UK emissions) and life cycle emissions (for the drinks), they demonstrate the significance of the sector's contribution to the total GHG emissions.

It can also be observed that the carbonated soft drinks and beer sub-sectors are the largest contributors to the GWP (42% and 40%, respectively) mainly due to significantly higher consumption volumes compared to the other beverage categories. It is also interesting to note that the Scotch whisky sub-sector contributes only 2% to the sectoral GWP despite having the highest carbon footprint per unit of product (57% higher than the second highest option wine; see Figure 6-2 and Figure 8-3). This is due to the fact that significantly less Scotch whisky is consumed in the UK than the other types of beverages. For example, total annual domestic consumption of Scotch whisky for the reference year stood at 25.8 million litres (Scotch Whisky Association, 2010) compared to 6,400 million litres for carbonated soft drinks (BSDA, 2011). Consumption of bottled water and wine, on the other hand, contributes around 10% and 7%, respectively to the total GWP from the beverage sector.

[35] The total consumption volume for the spirits and other alcohol sub-sectors has not been determined due to lack of data. For the hot-drinks sub-sector, which is dominated by instant coffee and black tea, the products are sold in the form of granules or powder and tea bags therefore, it has not been possible to determine the total consumption volume for the hot drinks sub-sector.

Consumption of energy, which is closely linked to the GWP, is also a key environmental issue for industry, government and consumers. The total primary energy demand for the five sub-sectors has been estimated at 73,000 TJ. Similar to the findings for the GWP, the carbonated soft drinks and beer sub-sectors are the major consumers of primary energy resources (42% and 39%, respectively) due to their relatively high consumption volumes. The bottled water and wine sub-sectors were responsible for 12% and 5%, respectively. Despite having the highest primary energy demand per 1,000 litres of product (54,600 MJ compared to the second highest option, wine 28,000 MJ; see Figure 6-10 and Figure 8-4), the Scotch whisky sub-sector accounts for around 2% of the primary energy demand from the beverage sector due to its relatively low domestic consumption volume.

As observed in Chapters 1 and 2, depletion of freshwater resources has been recognised as a critical issue for industry, governments and consumers both in the UK and on a global scale. This issue is even more critical for the beverage sector as water constitutes the key ingredient in beverage formulations. The total water consumption in the five sub-sectors has been estimated at 3.7 billion hl[36]. The carbonated soft drinks sub-sector accounts for the bulk of this impact, being responsible for around 71% of the beverage sector's 'total' water demand. As previously observed in Chapter 5, this is mainly due to production of the ingredients (most notably, sugar). The results also show that the beer and wine sub-sectors are responsible for 16% and 13%, respectively of this impact. As shown in Chapters 5 and 6, this is mainly due to water consumption for production of raw materials (notably, barley and grapes).

Regarding the issue of resource depletion, it can be seen in Figure 9-3 that the consumption of metals for the production of beverage packaging was around 126,200 tonnes in 2009/2010. Of this amount, the carbonated soft drinks and beer sub-sectors accounted for around 52% and 48% respectively. It can also be seen from Figure 9-3 that the UK beverage sector was responsible for the consumption of around 1 million tonnes of glass for the production of beverage packaging in 2009/2010. The beer sub-sector is the main consumer of glass, being responsible for 63% of the total consumption by the beverage sector. The carbonated soft drinks, bottled water and

[36] Water demand for uses other than in the beverage formulation has not been assessed for the bottled water sector due to lack of data.

wine sub-sectors are also important consumers of glass, being responsible for 15%, 11% and 9%, respectively. The Scotch whisky sub-sector, on the other hand, accounted for only 2% of the total glass consumption in 2009/2010. Total annual consumption of plastics for production of beverage packaging has been estimated at around 203,000 tonnes. Of this amount, the carbonated soft drinks and bottled water sub-sectors accounted for 70% and 30%, respectively. As the findings of the market analysis show, plastics are the preferred choice of packaging for the carbonated soft drinks and bottled water sub-sectors, while they are seldom used for packaging of wine, beer and Scotch whisky in the UK market.
As can also be seen in Figure 9-3, ADP from beverage sector amounted to over 21,000 tonnes Sb eq. for the reference year with the carbonated soft drinks and beer sub-sectors accounting for 42% and 36%, respectively. The bottled water, wine and Scotch whisky sub-sectors accounted for 15%, 10% and 1%, respectively due to total consumption volumes.

Regarding environmental impacts arising from emissions to air, the annual AP, ODP and POCP from the beverage sector have been estimated at over 17,000 tonnes DCB eq., 200,000 g R-11 eq. and 566,500 tonnes C_2H_4 eq., respectively. Similar to the other environmental impacts, the carbonated soft drinks and beer sub-sectors are the major contributors to AP, accounting for 39% and 36%, respectively. The wine, bottled water and Scotch whisky sub-sectors contribute 16%, 8% and 1%, respectively to the total AP. The annual ODP is dominated by beer and carbonated soft drinks, each sub-sector accounting for 44% and 38%, respectively. In contrast to the other environmental impacts, the carbonated soft drinks sub-sector is the dominant contributor to POCP, being responsible for over 98% of this impact due to the relatively large consumption volume. ODP from carbonated soft drinks production arises mainly from the emission of CF_2ClBr (Halon 1211) and $CBrF_3$ (Halon 1301) from manufacture of primary packaging.

Environmental impacts arising from emissions to water are represented by EP, FAETP and MAETP. As shown in Figure 9-3, the annual EP, FAETP and MAETP from the beverage sector have been estimated at over 12,000 tonnes PO_4 eq., 114,500 tonnes DCB eq. and 2,000 million tonnes DCB eq., respectively. EP is dominated by the carbonated soft drinks and beer sub-sectors, accounting for 50% and 43%, respectively, with the wine, bottled water and Scotch whisky sub-sectors accounting for 4%, 3% and 1%, respectively. The beer sub-sector is the major contributor to FAETP, accounting for 63% of this impact. Emission of nickel and vanadium from production of primary packaging materials are the key contributors to FAETP in the life cycle of beer (see Appendix 2, section A2.2). The bottled water, wine, carbonated soft drinks and Scotch whisky sub-sectors contribute around 18%, 10%, 8% and 1%, respectively to FAETP from the beverage sector. Similar to the majority of the environmental impacts, the carbonated soft drinks and beer sub-sectors are responsible for the largest contributions to MAETP, accounting for 50% and 39%, respectively. The contribution from the bottled water, wine and Scotch whisky sub-sectors is minimal, accounting for 7%, 4% and 0.5%, respectively.

Regarding environmental impacts arising from emissions to land, the annual TETP from the beverage sector has been estimated at over 23,000 tonnes DCB eq. with the beer sub-sector contributing 61% to the total. Emissions of chromium to agricultural soil from barley production are the key burden for TETP in the life cycle of beer (see Appendix 2, section A2.2). The carbonated soft drinks, bottled water, wine and Scotch whisky sub-sectors account for 23%, 12%, 4% and 0.3%, respectively.

The key economic impacts considered in the current study are annual total life cycle costs and value added. The annual life cycle costs for the sub-sectors considered in the study have been estimated at around £1.3 billion. The carbonated soft drinks and beer sub-sectors are the main contributors to this figure, accounting for 52% and 33%, respectively. The wine, bottled water and Scotch whisky sub-sectors, on the other hand, contribute 8% and 5%, respectively. Similar to most of the environmental impacts, the Scotch whisky sub-sector contributes a meagre 2% to the annual life cycle costs, despite having the second highest production cost per unit of product. As an illustration, the production costs per 1,000 litres of product for carbonated soft drinks (packaged in 0.75 l glass bottles), wine (packaged in 0.75 l glass bottles) and Scotch whisky (packaged in 0.70 l glass bottles) have been estimated as £373, £791 and £747, respectively (see Figure 9-2).

The economic value added for the UK beverage sector has been estimated at £15.8 billion annually, amounting to around 1% of total UK GDP[37] and around 11% of total Gross Value Added (GVA) from the UK manufacturing sector[38]. Similar to the abovementioned impacts, the CSD and beer sub sectors are the major contributors to the VA from the beverage sector, accounting for 42% and 40%, respectively. The bottled water, wine and Scotch whisky sub sectors, on the other hand, contribute 10%, 7% and 2%, respectively. It is crucial to note that the results shown in Figure 9-3 and discussed above are sensitive to domestic consumption volumes, and should be interpreted with care.

[37] Based on the stated UK GDP of £1,392,634 million for 2009 (Key Note, 2011: sourced from Economic and Labour Market Review, November 2010, National Statistics website.

[38] Based on the stated gross value added (GVA) generated by the UK manufacturing sector in 2009 (BIS, 2010).

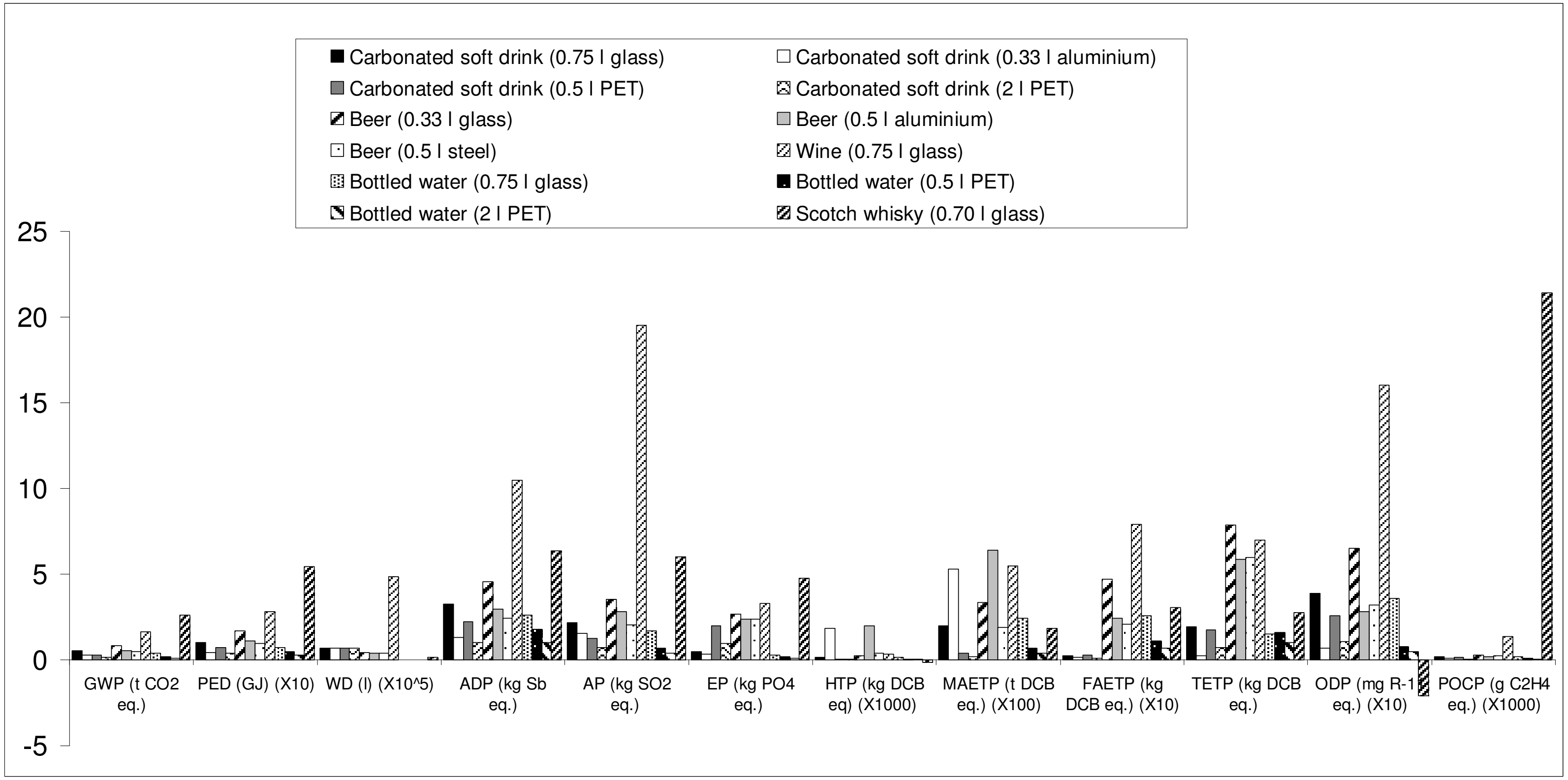

Figure 9-1 Life cycle environmental impacts of the drinks per 1000 litres

[*GWP* global warming potential, *PED* primary energy demand, *WD* water demand, *ADP* abiotic depletion potential, *AP* acidification potential, *EP* eutrophication potential, *HTP* human toxicity potential, *MAETP* marine aquatic ecotoxicity potential, *FAETP* freshwater aquatic ecotoxicity potential, *TETP* terrestrial ecotoxicity potential, *ODP* ozone depletion potential, *POCP* photochemical ozone creation potential. The scaled values should be multiplied with the factor shown in brackets against the relevant impact to obtain the original values.]

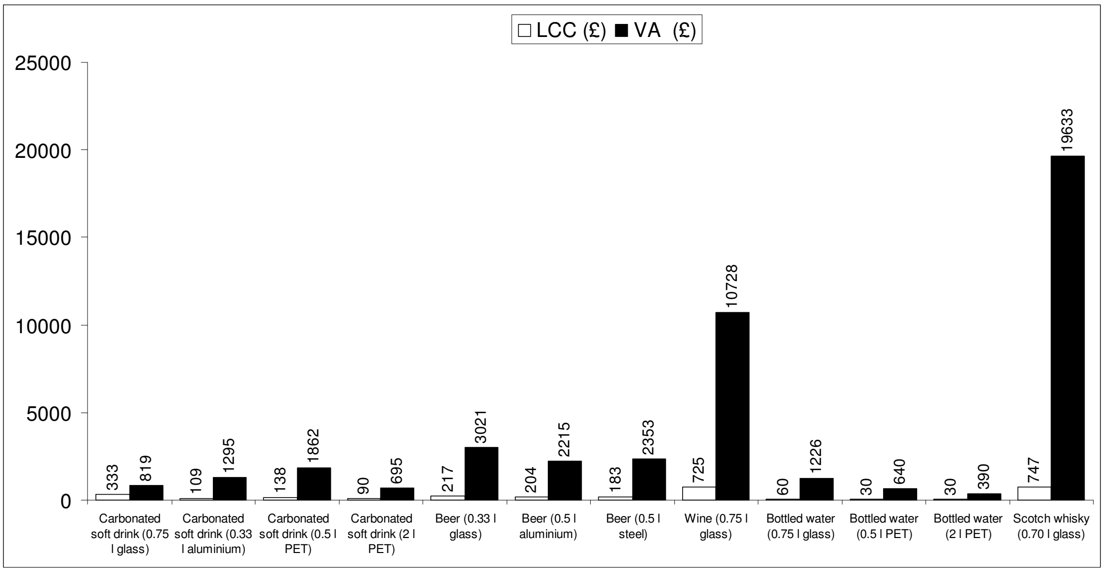

Figure 9-2 Life cycle costs and value added for all the drinks per 1000 litres

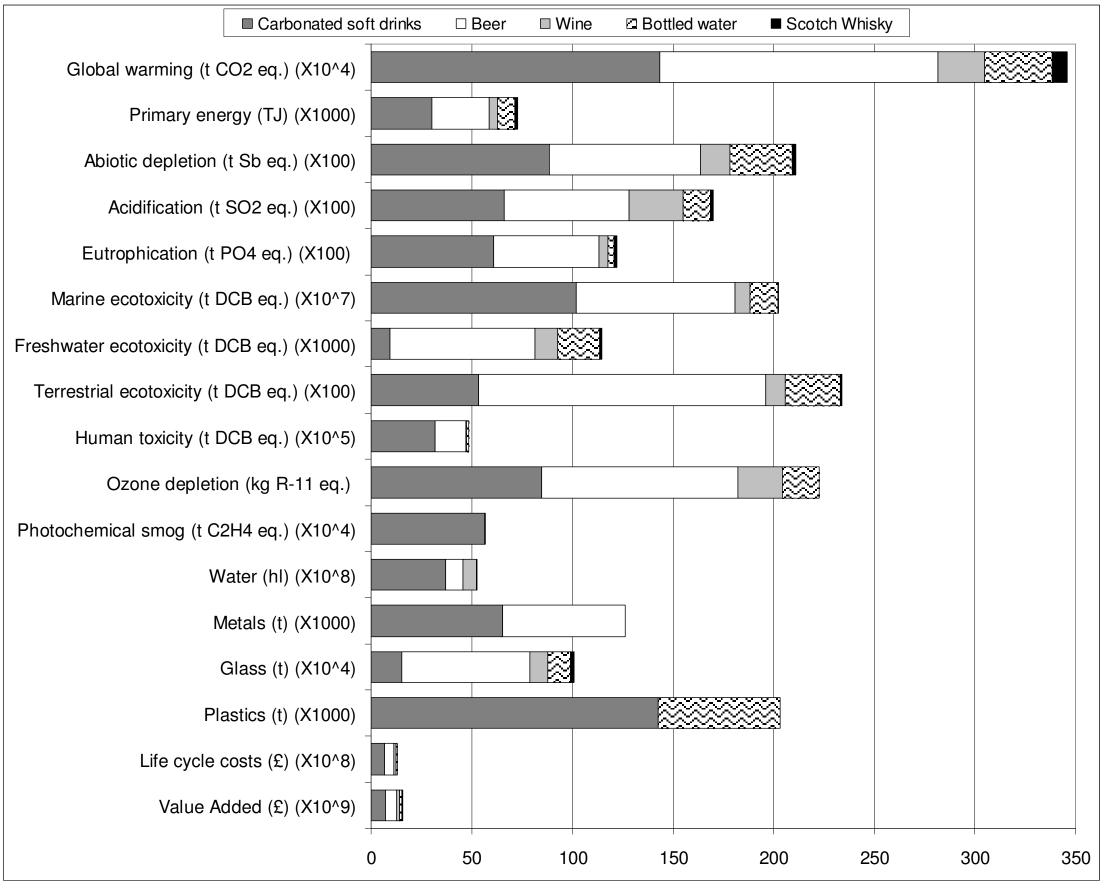

Figure 9-3 Environmental and economic impacts at the sectoral level for the drinks considered

[All values per year. The scaled values should be multiplied with the factor shown in brackets against the relevant impact to obtain the original values.]

9.1.1 Improvement opportunities

Having estimated the environmental and economic impacts of the different beverage products (at both supply chain and sectoral levels) and identified the 'hot spots' for these impacts, a number of improvement options have been considered as part of the sensitivity analysis. Some of the improvement options considered include reusing glass bottles, increasing the recycling rate and content of packaging, lightweighting of packaging, bulk shipping and bottling closer to the final market, as well as production of agricultural commodities based on alternative farming systems. In most instances, these options have been shown to improve the environmental and economic performance by reducing environmental impacts and total life cycle costs, while increasing economic value added for the actors in the supply chain. For example, it has been shown that by reusing glass bottles once, the life cycle GHG emissions in the carbonated soft drinks supply chain could be reduced by around 40%. It has also be shown that increasing the current UK PET recycling rate from 40% to 60%, would result in a 50% reduction in life cycle GHG emissions. Furthermore, increasing the recycling content and lightweighting of bottles were shown to result in significant improvements in the environmental and economic performance of the beer, wine and Scotch whisky sub sectors.

In addition to the sustainability improvement measures discussed in the preceding section, enterprises in the sector have been involved in introducing alternative types of packaging to markets in which they were previously not utilised. For example, attempts have been made to introduce the use of cans for packaging of wine (Rexam, 2012). One of the key environmental benefits that may be realised through this initiative is that of reduced life cycle GHG emissions (see Figure 4-2). Results obtained in this work also show lower environmental impacts for aluminium and steel cans than glass bottles in the areas of energy consumption, depletion of abiotic resources, acidification, eutrophication, freshwater and terrestrial ecotoxicity, ozone layer depletion and photochemical oxidant creation. However, the use of cans may also result in higher emissions of substances leading to human toxicity impacts (see Figure 4-10 and Figure 5-6. Economically, the results of the LCC suggest that the use of cans may result in lower life cycle costs for the beverage manufacturer (see Figure 4-19), as well as being more advantageous in terms of value added (see Figure 4-20).

These issues highlight the tradeoffs that may arise when adopting measures for sustainability improvements.

Regarding production of agricultural commodities based on alternative agricultural systems, the results of the LCA suggest that sugar from sugarcane has a lower GWP than sugar beet. However, sugar beet had a better environmental performance in impact categories such as FAETP, HTP, POCP, TETP and water consumption. A comparison of conventional and organic systems for cultivation of barley and wheat revealed tradeoffs and sometimes conflicting results from different studies regarding various environmental indicators (see Chapters 5 and 8). This suggests that a proper understanding of the complexity of environmental impacts from farming, as well as detailed assessments of economic and social aspects is required to provide a robust basis for decision-making in this area. In the subsequent sections of the current chapter, the social impacts which are relevant to the UK beverage sector are discussed.

9.2 Social sustainability assessment

As discussed in Chapter 3, the social indicators considered in this work have been motivated by the following issues: consumer health and wellbeing, the cost to society of treating beverage-related health issues, employment and wages, intergenerational aspects, provision of infrastructure for local communities as well as labour standards and human rights (see Table 3-1). The social issues which are relevant to the UK beverage sector are discussed first, followed by the intergenerational issues (global warming and abiotic resource depletion) and those based on international instruments and frameworks.

9.2.1 Sector-specific issues in the UK

9.2.1.1 Consumer health

Consumer health issues relevant to the beverage industry have been discussed extensively in literature. Among these issues, the growing problem of obesity has to some extent been attributed to the consumption of beverages containing high amounts of simple sugars and high-fructose corn syrup (HFCS) (Bray et al., 2004). As discussed in section 2.2.1.1, the incidence of obesity has almost trebled in the last 20 years, while it has been estimated that in 2006, 22% of the UK population was obese (EIRIS, 2006). More recent figures from 2010 reveal that 62.8% of adults (aged 16 or over) and 30.3% of children (aged 2 to 15) in England were overweight or obese (Department of Health, 2012). Forecasts have also suggested that, from current trends, 60% of men and 50% of women in the UK will be obese by 2050 (El-Sayed et al., 2012). Obesity has been associated with other health issues including cardiovascular diseases (Wilson et al., 2002), diabetes (Mokdad et al., 2001), cancer (Veer and Kampman, 2007; Calle et al., 2003; Møller et al., 1994), stroke (Suk et al., 2003) and depression (Onyike et al., 2003) as well as adverse social consequences through discrimination, social exclusion and loss of earnings (NHS, 2010). Alcoholic beverage consumption has also been causally linked to over 60 different medical conditions and around 40% of the global disease burden (Room et al., 2005), including cancer, neuropsychiatric disorders, gastrointestinal diseases and alcohol-induced injuries (WHO, 2002; Rehm et al., 2003).

As shown in Table 2-2, strategies adopted by the government and the beverage industry for tackling health issues arising from beverage consumption include product labelling regarding calorific and alcohol content, provision of natural, functional, diet and low calorie drinks (BSDA, 2011; Department of Health, 2011). The substitution of sugar for artificial sweeteners (e.g. aspartame, acesulfame potassium and sucralose) in diet drinks has however, led to concerns about the potential carcinogenicity of some artificial sweeteners; for example the study by Soffritti et al. (2005) which found more lymphomas and leukaemia in rodents fed high doses of aspartame. However, further studies by the European Food Safety Authority (EFSA, 2009), the US National Cancer Institute (NCI, 2009) and Lim et al. (2006) found no evidence that aspartame increases the risk of cancer or poses any other threat to human health. Furthermore, Hendriksen et al. (2010) found that substitution of added sugar by intense sweeteners in carbonated soft drinks has beneficial effects on body mass index (BMI) and reduction of tooth decay, with no apparent adverse health effects in young adults. The findings in the abovementioned studies suggest that substitution of sugar by sweeteners in beverages has the potential to reduce the adverse health effects associated with high sugar intake from beverages. However, there still exists a need for detailed investigations, following a risk-benefit approach, into the potential health implications of substitute ingredients in beverage formulations.

The issue of the nutritional value of beverages is an important health aspect which has not been widely discussed within the framework of sustainability assessments. Table 9-1 provides the nutritional value for the five beverages considered in this work. It can be seen that, per litre of beverage, whiskey has the highest calorie content (2,367 kcal per litre) while bottled water has no calorific content. The sugar content of carbonated soft drinks is particularly interesting when analysed in relation to total consumption per capita in the UK. For example, daily consumption of 0.28 litres[39] of carbonated soft drinks accounts for 26 g of sugar or 25% of the recommended guideline daily amount (GDA) for an average adult. For children, this amounts to 31% of the recommended GDA[40]. This has potentially significant implications on the health of consumers.

Table 9-1 Guideline daily amounts of calories and nutrients and the nutritional value of the beverages considered in this study

	Nutrient value per litre of beverage[a]					
Calories and nutrients	**Guideline daily amounts (GDA) for an average adult[b]**	**Carbonated soft drinks**	**Beer (lager)**	**Red wine**	**Bottled water**	**Whiskey**
Calories	2,250 kcal	371 kcal (16.5%)	440 kcal (19.5%)	846 kcal (37.6%)	0.0 kcal	2,367 kcal (105%)
Protein	50 g	0.1 g (1.4%)	4.7 g (9.4%)	0.7 g (1.4%)	0.0 g	0.0 g
Carbohydrate	265 g	99 g (37.4%)	36 g (13.4%)	26 g (9.8%)	0.0 g	1.0 g (0.4%)
Sugars	105 g	93 g (88.6%)	0.0 g	6.1 g (5.8%)	0.0 g	1.0 g (1.0%)
Fat	82.5 g	0.3 g (0.4%)	0.0 g	0.0 g	0.0 g	0.0 g
Saturates	25 g	0.0 g	0.0 g	0.0 g	0.0 g	0.0 g
Fibre	24 g	0.0 g	0.0 g	0.0 g	0.0 g	0.0 g
Salt	6 g	0.0 g	0.0 g	0.0 g	0.0 g	0.0 g

[a]The nutrient values have been sourced from the US Department of Agriculture (USDA) National Nutrients Database model (USDA, 2010).
[b]Guideline daily amounts (GDA) of calories and seven other main nutrients sourced from the Food and Drink Federation website (FDF, 2012).

[39] Estimated based on the stated per capita consumption of carbonated soft drinks of 103 litres in 2010 (see section 2.2.1.1).
[40] The recommended GDA for sugars for children (aged 5-10 years) is 85 g (FDF, 2012).

9.2.1.2 Human toxicity

In addition to obesity and alcoholism, another health issue is related to the toxic emissions along the beverage supply chain. These have been quantified using human toxicity potential (HTP) as an indicator estimated within LCA (see Figure 9-3). This approach has also been applied in other studies including Dorini et al. (2010) and Stamford and Azapagic (2011). As can be seen in Figure 9-3, the total HTP from the beverage sector has been estimated at over 4.8 million tonnes DCB eq. annually. The carbonated soft drinks and beer sub-sectors are the major contributors to this impact, being responsible for 66% and 31%, respectively of the total. The major burdens for HTP in the carbonated soft drinks and beer life cycles are atmospheric heavy metal emissions (arsenic, chromium and selenium) from manufacturing of primary packaging materials (see Appendix 2, sections A2.1 and A2.2). The relative contributions from the bottled water, wine and Scotch whisky sub-sectors are minimal (less than 2% each) due to their relatively low consumption volumes compared to carbonated soft drinks and beer sub-sectors.

9.2.1.3 Government expenditure of consumer health issues

The consequences of obesity and alcoholism are not limited to consumer health problems as they also have significant economic implications. For example, in 2002, the direct cost to the National Health Service (NHS) of treating obesity in England was estimated at between £46 and £49 million and between £945 and £1.1 billion for treating the consequences of obesity (NHS, 2006, 2010). In Scotland, the costs for treating obesity and its consequences in 2007/2008 have been estimated at £175 million (NHS, 2010; Scottish Government, 2010). Due to a lack of data, it is not possible to relate this expenditure to the drinks sector alone. However, the economic impacts of alcohol misuse are estimated to cost the NHS in England £2.7 billion in 2006/2007 (NHS, 2012) while the annual cost impact in Scotland has been estimated at £3.6 billion (Scottish Government, 2012). To put this in perspective, this equates to around 70% of the total UK government revenue from alcohol duties in 2009/2010[41].

[41] Estimated based on the stated UK government revenue from alcohol duties of £9 billion in 2009/10 (Collis et al., 2010).

9.2.1.4 Employment and wages

In 2009, the total number of people employed in the UK manufacturing sector was estimated at around 2.6 million, representing just over 8% of total employment in the UK (BIS, 2010). The food, beverages and tobacco industry was the largest employer in the UK manufacturing sector, accounting for just under 16% of total employment in 2009 (BIS, 2010). Although specific employment figures for the beverage sector have been difficult to obtain, it can be inferred that the beverage sector is a significant employer of labour in the UK. For example, as discussed in Chapter 2, the workforce in the UK soft drinks, beer and Scotch whisky industries amounts to around 36,000 people (BSDA, 2011; BBPA, 2010; Scotch Whisky Association, 2010). This equates to 1.4% of the total manufacturing workforce or around 9%[42] of total employment in the UK food, beverages and tobacco industry. With regard to wages, the rate of pay and benefits for workers in the UK beverage sector would be similar to other manufacturing sectors depending on the specific roles performed. The Office for National Statistics (ONS) observes that the median gross annual earnings for full-time employees across all sectors in the UK were £26,200, an increase of 1.4% from 2010 (ONS, 2011). It can be argued that this compares favourably with the minimum income standard (MIS)[43] of annual earnings of £15,000 (before tax) for a single working-age person (JRF, 2011).

9.2.2 Intergenerational issues

9.2.2.1 Global warming potential (GWP)

Climate change is one of the key intergenerational issues and its mitigation is an imperative for sustainable development. In this work, GWP estimated as part of LCA is used as an indicator of climate change-related impact. As discussed in Section 9.1, beverage consumption in the UK is estimated to be responsible for around 3.5 million tonnes of CO_2 eq. emissions annually, with the carbonated soft drinks and beer sub-sectors being the largest contributors. The current study has also shown that

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[42] Based on the following estimates: number of people employed in the UK food, beverages and tobacco (FBT) industry - just under 16% of total manufacturing employment in 2009; total manufacturing sector employment of 2.6 million in 2009 (BIS, 2010); assuming total FBT industry accounts for 15% of total manufacturing sector employment in the absence of specific figures.

[43] The minimum income standard (MIS) is defined as the "minimum income that people need in order to reach a minimum socially acceptable standard of living in the UK today, based on what members of the public think. It is calculated by specifying basket of goods and services required by different types of household in order to meet these needs and participate in society" (JRF, 2011).

reductions in GWP can be achieved through increased recycling, lightweighting, alternative types of packaging, and alternative agricultural systems. Therefore, these options should be prioritised within the sector as the main climate change mitigation measures.

9.2.2.2 Abiotic depletion potential (ADP)

In addition to climate change, depletion of abiotic resources has been identified as a key intergenerational issue. Abiotic depletion potential (ADP), estimated as part of LCA, has been used as an indicator of depletion of abiotic resources in this work. As discussed in section 9.1, ADP from beverage sub-sectors considered amounted to over 21,000 tonnes Sb eq. for the reference year with the carbonated soft drinks and beer sub-sectors accounting for 42% and 36%, respectively. The bottled water, wine and Scotch whisky sub-sectors accounted for 15%, 10% and 1%, respectively due to total consumption volumes. Similar to the other environmental impacts, the current study has demonstrated that reductions in ADP can be achieved through improvement strategies such as increased recycling, lightweighting, alternative types of packaging and alternative agricultural systems. These measures should therefore, be prioritised within the sector for mitigation of this impact.

9.2.3 Social issues based on international instruments and frameworks

This section presents the social risk assessment related to the indicators which are derived from international social sustainability instruments and frameworks. The indicators are discussed based on their risk characterisation at the country level. The countries involved in the UK beverage supply chain and their associated production activities (based on the five beverages considered) are summarised below:

- Australia: cultivation of wine grapes, production and bottling of red wine;
- China: sourcing of caffeine for carbonated soft drinks production;
- Colombia: sourcing of citric acid for carbonated soft drinks production;
- Denmark: sourcing of barley for Scotch whisky production;
- France: sourcing of maize for Scotch whisky production;
- India: recycling of used aluminium beverage cans;
- Mauritius: cultivation of sugar cane and production of sugar for carbonated soft drinks production;

- Netherlands: sourcing of sodium benzoate for carbonated soft drinks production; and
- UK: cultivation of barley and wheat for beer and Scotch whisky production; production of beverage ingredients such as phosphoric acid, sodium hydroxide and sulphuric acid; production of primary and secondary packaging materials including glass and PET bottles, aluminium and steel cans; production of utilities including electricity and water; beverage production, storage and retail, as well as waste management of in-process and post-consumer waste.

Following the methodology outlined in Chapter 3, section 3.4.3, the results of the social risk assessment are given in Figure 9-4 as an indication of what countries in the UK beverage supply chain may represent the ‘hot spots’. The risk characterisation criteria for the indicators as specified in the social hot spots database (SHDB, 2010) are given in Chapter 3, section 3.2.2.3. After determining the risk profile for each country in the beverage supply chain for the relevant social indicators, each risk category was then assigned arbitrary numerical values from 0 (representing no evidence) to 5 (representing very high risk) of a social impact occurring as shown in Table 9-2. The social risk profiles for each country in the UK beverage supply chain was then depicted on a spider plot as shown in Figure 9-4. More details on the social indicators are provided in the subsequent sections.

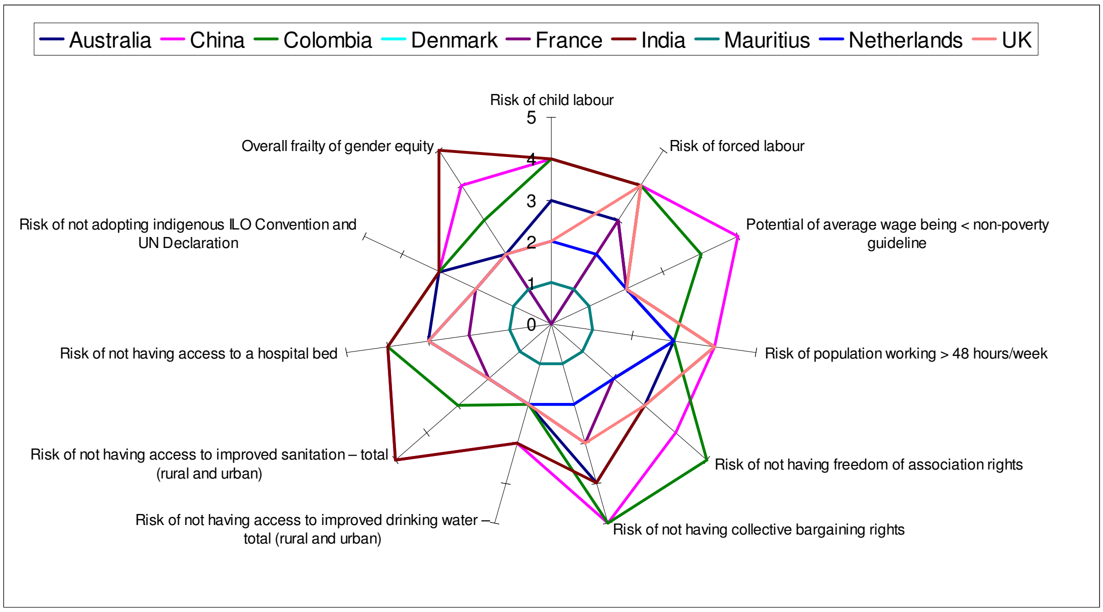

Figure 9-4 Social risk profiles in the life cycle of the UK beverage supply chain
[The following values have been adopted for scaling of the plot in this work, *0* no evidence, *1* no data available, *2* low risk, *3* medium risk, *4* high risk and *5* very high risk]

Table 9-2 Characterisation of social risks in the life cycle of the UK beverage sector

Social indicator	Countries in the UK beverage supply chain								
	Australia	China	Colombia	Denmark	France	India	Mauritius	Netherlands	UK
Risk of child labour	3	4	4	0	0	4	1	2	2
Risk of forced labour	3	4	4	2	3	4	1	2	4
Potential of average wage being < non-poverty guideline	2	5	4	2	2	2	1	2	2
Risk of population working > 48 hours per week	3	4	3	3	3	4	1	3	4
Risk of not having freedom of association rights	3	4	5	2	2	3	1	2	3
Risk of not having collective bargaining rights	4	5	5	2	3	4	1	2	3
Risk of not having access to improved drinking water	2	3	2	2	2	3	1	2	2
Risk of not having access to improved sanitation	2	5	3	2	2	5	1	2	2
Risk of not having access to a hospital bed	3	4	4	3	2	4	1	3	3
Risk of not adopting indigenous ILO convention and UN Declaration	3	3	3	2	2	3	1	2	2
Overall frailty of gender equality	2	4	3	2	2	5	1	2	2

[The following values have been adopted for scaling of the plot in this work, *0* no evidence, *1* no data available, *2* low risk, *3* medium risk, *4* high risk and *5* very high risk]

9.2.3.1 Child labour

The International Labour Organisation (ILO) estimates that globally, around 215 million children work (many of them full-time), depriving them of formal education and exposing some to hazardous environments (ILO, 2012a). From Figure 9-4, it can be seen that there exists a high risk of the use of child labour in China and Colombia, from which caffeine and citric acid are sourced, as well as India, where used aluminium cans are sent for recycling. These countries are classified as high risk due to the finding that around 10 to 20% of the population of children are engaged in different forms of labour (SHDB, 2010). The risk of child labour in the other countries associated with the UK beverage sector ranges from low (less than 4% in the UK and Netherlands) to medium (around 4 to 10% in Australia). No evidence has been found for Denmark and France, while data for Mauritius have not been available.

9.2.3.2 Forced labour

The most recent estimates by the ILO indicate that as many as 21 million people globally are victims of forced labour (ILO, 2012b)[44], highlighting the critical nature of this issue. The results in Figure 9-4 indicate that China, Colombia, India and the UK are the hot spots, with a high-risk classification. The abovementioned countries are classified as high risk based on the finding that forced labour is indicated in two or more sources of information including the US Department of State Reports on Human Rights, the US Department of Labour List of Goods Produced by Child Labour or Forced Labour, UNHCR Report of Trafficking in Persons and information from the ILO (SHDB, 2010). Australia and France have been identified as having medium risk (forced labour indicated in one of the main sources), while Denmark and the Netherlands have been classified as low risk (minimal evidence from available sources). Similar to child labour, data have not been available for Mauritius.

9.2.3.3 Wage assessment

In the UK drinks supply chain, China and Colombia have been identified as the key hot spots for this indicator, with risk characterisations of very high and high

[44] The term forced labour is used by the international community to denote situations in which the persons involved are made to work against their free will, coerced by their recruiter or employer, for example through violence or threats of violence, or by more subtle means (ILO, 2012b).

respectively. It has been estimated that above 50% of the population in China and around 10 to 50% of the population in Colombia live on less than $2/day (SHDB, 2010). Australia, Denmark, France, India, Netherlands and the UK have all been characterised as low risk for this impact (less than 2% of the population live on less than $2/day). Data for Mauritius have not been available.

9.2.3.4 Excessive working time

For this indicator, China, India and the UK are the key hotspots, being characterised as high risk, as shown in Figure 9-4. It has been estimated that around 25 to 50% of the labour force in the abovementioned countries work more than 48 hours/week (SHDB, 2010). Australia, Colombia, Denmark, France, and Netherlands are characterised as medium risk, with only 10 to 25% of the labour force working more than 48 hours/week (SHDB, 2010), while there are no data for Mauritius.

9.2.3.5 Freedom of association

The key hot spots for risk to freedom of association are China and Colombia, being characterised as high (<3.5) and very high (≥3.5) risk, respectively. The characterisation is based on the probability that the abovementioned countries do not offer provisions for freedom of association rights (for more detail on the risk classification criteria, see section 3.2.2.3). Australia, India and the UK are characterised as medium risk (<3.5), while Denmark, France and the Netherlands are characterised as low risk (<2.5). Data for Mauritius have not been available.

9.2.3.6 Collective bargaining rights

The results in Figure 9-4 show that Australia, China, Colombia and India are the hot spots regarding the risk to collective bargaining rights. China and Colombia have been characterised as very high risk (risk factor of >3.5), while Australia and India are characterised as high risk (<3.5) based on the probability that the countries in question do not offer provision for collective bargaining rights. France and the UK are characterised as medium risk (<2.5), while Denmark and the Netherlands are classified as low risk (<1.5). More detail on the criteria for classification of this risk is given in section 3.2.2.3. Data for Mauritius have not been available.

9.2.3.7 Community infrastructure

This impact evaluates, through three indicators, access to community services and infrastructure in the host countries for unit processes in the beverage supply chain. The first two indicators (risk of not having access to improved drinking water and sanitation) take into account both rural and urban populations in the host countries, while the risk of not having access to a hospital bed does not make a distinction between populations in rural and urban areas.

Improved drinking water

Regarding the risk of not having access to improved drinking water, no significant risks have been identified in the supply chain. China and India are characterised as medium risk countries (>87% of the rural and urban population have access to improved drinking water sources), while all the other countries (except Mauritius for which data are not available) are characterised as low risk (>91% of the rural and urban population have access to improved drinking water sources).

Improved sanitation facilities

Access to improved sanitation is a key issue in China and India, both being characterised as very high risk countries (≥0% of the rural and urban population have access to improved sanitation facilities). Colombia is characterised as medium risk (≥64% of the rural and urban population have access to improved sanitation facilities), while Australia, Denmark, France, the Netherlands and the UK are characterised as low risk (≥77% of the rural and urban population have access to improved sanitation facilities).

Hospital beds

The risk of not having access to a hospital bed is a crucial issue for China, Colombia and India, all being characterised as high risk countries (<3 beds/1,000 people). Australia, Denmark, the Netherlands and the UK are characterised as medium risk (>3-5 beds/1,000 people), while France is characterised as low risk (>5 beds/1,000 people) for this impact.

9.2.3.8 Indigenous rights

Indigenous rights are related to the adoption of the ILO Convention and the UN Declaration on the Rights of Indigenous Peoples (UN, 2007). No significant hot spots have been identified in the beverage supply chain. As can be seen in Figure 9-4, Australia, China, Colombia, and India have been characterised as medium risk (countries that have not ratified the ILO Convention 169 and have abstained from signing the UN Declaration), while Denmark, France, the Netherlands and the UK are characterised as low risk (countries with an indigenous population that have ratified the ILO Convention 169 and endorsed the UN Declaration).

9.2.3.9 Gender equality

China and India are the key hot spots for impacts in the area of gender equality, being characterised as high (risk factor of 2.3 – 3.3) and very high (risk factor of >3.3) risk, respectively. Colombia is characterised as medium (risk factor of 1.3 – 2.3) risk for gender equality while Australia, Denmark, France, the Netherlands and the UK are classified as low risk (risk factor of <1.3). As previously observed in section 3.2.2.3, characterisation of this indicator is based on a weighted average of different indices such as the Social Institutions and Gender Index (SIGI), Global Gender Gap (GGG), Gender Related Development Index (GDI) and Gender Empowerment Measure (GEM) (SHDB, 2010).

In summary, based on the above analysis of the social issues in the drinks supply chain, the countries most at risk to be hot spots are summarised in Table 9-3. The industrial sectors associated with the UK beverage supply chain in the high risk countries should therefore, be the focus of more detailed investigations into social issues highlighted. These countries should also be the focus of external corporate social responsibility initiatives by manufacturers in the UK beverage sector.

Table 9-3 Summary of countries most at risk to be hot spots in the UK beverage supply chain based on the results in Figure 9-4

Social issue	Countries in the beverage supply chain to be aware of
Risk of child labour	China, Colombia, India
Risk of forced labour	China, Colombia, India, UK
Potential of average wage being < $2/day (wage assessment)	China, Colombia
Risk of population working > 48 hours/week (excessive working time)	China, India, UK
Risk of not having freedom of association rights	China, Colombia
Risk of not having collective bargaining rights	Australia, China, Colombia, India
Risk of not having access to improved drinking water (community infrastructure)	N/A
Risk of not having access to improved sanitation (community infrastructure)	China, India
Risk of not having access to a hospital bed (community infrastructure)	China, Colombia, India
Risk of country not adopting ILO Convention and UN Declaration (indigenous rights)	N/A
Overall frailty of gender equality	China, India

9.3 Summary

The sustainability impacts of the UK beverage sector have been estimated based on the results of the sub-sectors discussed in the previous five chapters. The results of the environmental sustainability assessment indicate that these five sub-sectors are responsible for around 3.5 million tonnes of CO_2 eq. emissions annually, representing 30% of the GHG emissions from the food and drink sector and around 0.6% of total UK emissions. The annual primary energy and water demand have been estimated at 73,000 TJ and 3.7 billion hl, respectively. The annual demand for materials used for the manufacture of beverage packaging has been estimated at around 126,250 t of metals, 1 million t of glass and 203,000 t of plastics.

Based on the results of the economic sustainability assessment, the annual life cycle costs and value added have been estimated at £1.3 and £15.8 billion, respectively. It has also been estimated that the five beverage sub-sectors contribute around 1% of the UK GDP as well as 11% of the total GVA from the UK manufacturing sector. Among the sub-sectors analysed in this work, the carbonated soft drinks and beer sub-sectors are the major contributors to the sectoral impacts mainly due to relatively high consumption volumes in relation to the other beverage categories.

From the social point of view, the contribution of the beverage industry to consumer health issues such as obesity and alcoholism has been discussed. For example, it has been estimated that the annual costs of treating obesity and its consequences in England and Scotland could be in excess £1 billion. Although it is not possible to estimate how much of this is due to the consumption of drinks, its contribution is probably important. Furthermore, the annual costs of treating alcoholism and its consequences have been estimated at around £3.6 billion. Another health-related issue, human toxicity, has been estimated at over 4.8 million tonnes of DCB eq. emissions per year. The social risk assessment shows that China, Colombia and India are the key hot spots for social issues in the life cycle of the UK beverage sector, offering significant social risk as well as opportunities for a robust and holistic approach to address relevant social issues in the regions which are most affected.

The analysis and discussion in this chapter as well as the preceding five chapters have shown that the UK beverage sector contributes to various sustainability impacts. The sensitivity analyses carried out have also highlighted the scope for sustainability improvements that can be implemented to improve sustainability in the beverage sector. These include increased recycling, lightweighting, use of alternative packaging materials, alternative agricultural systems, as well as alternative beverage ingredients.

In earlier sections of this work, it has been observed that there is currently no integrated assessment methodology for sustainability assessment of the beverage sector and that one is required if any level of sustainability is to be achieved in this sector. The integrated sustainability assessment methodology developed in this work has demonstrated its usefulness for this purpose by helping to establish performance benchmarks against which improvement options can be assessed as well as identifying potential tradeoffs and win-win situations. The methodology has also demonstrated how the scope of the conventional product-based LCA and LCC methodologies can be expanded to estimate the life cycle impacts of an industrial sector using a bottom-up approach. It is hoped that the discussions presented in this work will be a useful contribution in helping the UK beverage sector achieve the goals of sustainable development.

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10 CONCLUSIONS

The work presented in this dissertation represents an attempt to develop a methodology and assess the sustainability assessment in the UK beverage sector. The methodology has been based on a life cycle approach, considering the impacts of the beverage supply chain from extraction of raw materials to final waste disposal. Life cycle assessment (LCA) has been used for the environmental sustainability assessment, while life cycle costing (LCC) and value added (VA) have been used for the economic sustainability assessments. The discussion of social aspects of the beverage sector has included direct impacts in the UK such as health and employment as well as supply chain issues such as country-level social hot spot assessment. Furthermore, it has been shown how the scope of the product-based LCA and LCC methodologies can be expanded to estimate the life cycle impacts of an industrial sector using the bottom-up approach rather than the top-down approach typically applied for this purpose.

The objectives of this research have been met in that:

i. The UK beverage sector has been reviewed and the main sustainability issues have been identified;
ii. The life cycle environmental and economic impacts have been estimated for five different beverage sub-sectors in the UK beverage sector: carbonated soft drinks, beer, wine, bottled water and Scotch whisky; the hot spots for these impacts have been identified; the environmental and economic impacts of different types of packaging used in the UK market have been compared; and the impact of improvement options on the environmental and economic sustainability performance of the supply chains assessed;
iii. A novel, quantitative bottom-up approach has been developed and applied for the estimation of the life cycle impacts of the five sub-sectors which comprise the UK beverage sector by combining life cycle assessment and life cycle costing with market analysis;
iv. The approach has been used to estimate the life cycle impacts at the level of the UK beverage sector, to demonstrate its usefulness for successfully

quantifying the impacts for an industrial sector and identifying more sustainable practices; and

v. A number of social aspects relevant to the UK beverage sector have been identified and highlighted and a social hot spot assessment has been carried out identifying the countries most likely to pose social risks in the beverage supply chain.

10.1 General conclusions

A number of general conclusions can be drawn from the results of this work:

i. The UK beverage sector is a major contributor to a number of positive and negative impacts which affect sustainable development in the manufacturing sector and in the UK as a whole. Some of these impacts include annual GHG emissions in excess of 3.5 million tonnes CO_2 eq.; annual energy and water demand in excess of 73,000 TJ and 3.7 billion hl, respectively; annual metals, glass and plastics consumption of over 126,000 tonnes, 1 million tonnes and 200,000 tonnes respectively; annual life cycle costs and value added of over £1.3 billion and £15.8 billion, respectively; annual costs of treating health impacts (alcoholism) of around £3.6 billion; and employment of over 36,000 people; China, Colombia and India are the key hot spots in the life cycle of the UK beverage sector, offering significant social risks as well as opportunities to address the relevant social issues in the affected regions.

ii. The carbonated soft drinks and beer sub-sectors are the major contributors to the environmental and economic impacts mainly due to their significantly greater annual consumption volumes compared to the other beverages.

iii. Manufacturing of primary packaging and production of raw materials (beverage ingredients) are the key life cycle stages in the beverage sector with regard to the environmental and economic burdens and impacts. The transportation stage makes only a small contribution to the environmental burdens and impacts despite the widely publicised debate about food miles.

iv. With regard to packaging, substantial environmental advantages could be gained from optimisation of beverage packaging systems through lightweighting, increasing recycling and recycled content, as well as materials substitutions. This would also result in improvements of economic performance through reduced life cycle costs and increased value added.

v. Regarding the raw materials, using alternative ingredients or displacing conventionally produced agricultural commodities by organic may reduce some environmental impacts but may also increase others so that trade offs are necessary.

10.2 Specific conclusions

The specific conclusions that can be drawn from this work are related to the supply chains and sub-sectors of the five beverages considered in this work: carbonated soft drinks, beer (lager), wine (red), bottled water and Scotch whisky.

Carbonated soft drinks

i. The carbonated soft drinks sub-sector is a significant contributor to various sustainability impacts including the annual GWP of over 1.4 million tonnes of CO_2 eq., energy and water demand of around 30,000 TJ and 3.7 billion hl, respectively and annual value added of around £7 billion.

ii. The key life cycle stages that should be targeted for environmental improvements are production of packaging (particularly the primary packaging materials – glass and PET bottles) and production of ingredients (particularly cultivation of sugar cane).

iii. Per unit of product, the drink packaged in the 2 l PET bottle has the lowest impact for most of the environmental impact categories while the drink packaged in the glass bottle is the least preferred option for most environmental impact categories. For example, the GPW for the former is 151 g CO_2 eq./l and for the latter 555 g CO_2 eq./l.

iv. Per unit of product, the drink packaged in the 2 l PET bottle also has the lowest life cycle costs (£0.091/l), while the drink packaged in the glass bottle has the highest life cycle costs (£0.37/l). On the other hand, the drink packaged in the 0.5 l PET bottle has the highest value added (£1.86/l), while the drink packaged in the 2 l PET bottle has the lowest value added (£0.70/l).

v. Compared to the current operations in the supply chain, the improvement options investigated – reusing the glass bottles and increasing the PET recycling rate – improve the environmental performance with regard to the GWP.

vi. Production of sugar from sugar beet as opposed to the current operation which utilises sugar from sugar cane, has the potential to increase GWP, AP, EP, MAETP, ODP and ADP, while reducing FAETP, HTP, POCP, TETP and water consumption.

vii. Refrigeration of the drinks at retailer contributes significantly to the GWP and should be discouraged, particularly as carbonated drinks are not perishable goods.

viii. The improvement options investigated (reusing glass bottles and increasing the recycling rate of PET) would necessitate major changes in infrastructure required for collection and cleaning of used glass bottles as well as collection of used PET bottles and recycling to acceptable standards for beverage applications. It is expected that these changes would result in significant economic implications for the stakeholders in the beverage sector, including manufacturers, retailers, consumers and government.

Beer (lager)

i. The beer sub-sector generates an annual GWP of around 1.4 million tonnes CO_2 eq. It also uses over 28,000 TJ of energy and has a water demand of 863 million hl. The total annual value added is estimated at around £5.6 billion.

ii. The key life cycle stages that should be targeted for environmental improvements are production of primary packaging materials – glass bottles, aluminium and steel cans, and production of raw materials (particularly barley).

iii. Per unit of product, beer packaged in the steel can has the lowest impacts for most of the environmental categories while the glass bottle has the highest. For example, the GPW for the beer in steel can is 487 g CO_2 eq./l and in the glass bottle 819 g CO_2 eq./l.

iv. Per unit of product, beer packaged in the glass bottle has the highest value added (£3.02/l), while the product packaged in the steel can has a marginally higher value added (£2.35/l) than that packaged in the aluminium can (£2.22/l).

v. The improvement options investigated for packaging (increasing the recycled content and lightweighting of the glass bottles) indicate an improvement in the overall environmental and economic performance of the supply chain. However, implementing these options would require changes in the infrastructure for improving collection and recycling of post-consumer packaging. Furthermore, as the rate of glass recycling is already quite high (85%), increasing this further may be difficult. However, significant improvements in recycling of steel and aluminium cans could still be achieved.

vi. Compared to the current operations, use of organic barley has the potential to reduce GWP, FAETP, HTP, MAETP, POCP, ODP, ADP and water consumption, while increasing AP, EP and TETP.

Red wine

i. Consumption of Australian wines in the UK contributes the annual GWP of around 230,000 tonnes CO_2 eq., energy and water demand of over 3,800 TJ and 673 million hl, respectively, and annual value added of around £1.5 billion.

ii. The key life cycle stages that should be targeted for environmental improvements are production of raw materials (notably cultivation of wine grapes), transport (particularly international shipping) and production of packaging (particularly glass bottles).

iii. Compared to the current operations in the supply chain, organic production of grapes has the potential to reduce PED, ADP, TETP, ODP and POCP, while increasing AP and EP.

iv. Shipping wine in bulk and bottling closer to the final market should be considered as it offers the potential for significant environmental improvements.

v. The improvement options for packaging investigated in this work (increasing the recycled content and lightweighting of glass bottles, as well as use of carton packaging) would improve the overall environmental and economic performance of the supply chain. However, as mentioned above, the recycling rate of glass is already high, so there may be limited opportunities in improving this further. Moreover, this would create a further surplus of the green glass which already exists in the UK so that much of the glass is recycled into the aggregate rather than back into the bottles.

Bottled water

i. The UK bottled water sub-sector is responsible for the annual GWP of over 300,000 tonnes CO_2 eq. and annual primary energy consumption of over 8,000 TJ. Its value added is estimated at £1.2 billion per year.
ii. The key life cycle stage that should be targeted for environmental and economic improvements is production of packaging (particularly primary packaging – PET and glass bottles).
iii. Per unit of product, water packaged in the 2 l PET bottle has the lowest environmental impact for most impact categories while water packaged in the glass bottle has the highest value added per unit of product. For example, the GPW for the water in 2 l PET bottle is 112 g CO_2 eq./l and in the glass bottle 388 g CO_2 eq./l.
iv. Refrigeration of water at the retailer increases GWP significantly and therefore, should be discouraged. However, this may result in socio-economic implications such as reduced sales and revenue due to consumer preference.

Scotch whisky

i. The Scotch whisky sub-sector contributes to various sustainability impacts including annual GWP of around 75,000 tonnes CO_2 eq., annual primary energy and water demand of around 1,500 TJ and 4.1 million hl, respectively, as well as £506 million in annual value added.
ii. The key life cycle stages that should be targeted for environmental improvements are the manufacturing (particularly energy consumption), production of raw materials (particularly wheat) and production of packaging (particularly glass bottles);
iii. The introduction of technological improvements such as high gravity brewing has the potential to reduce the environmental impacts. However, it would result in cost implications for the manufacturer.

iv. Compared to the current operations, use of organic wheat has the potential to reduce GWP, FAETP, HTP, MAETP, POCP, ODP, ADP and water consumption, while increasing AP, EP and TETP.

v. Compared to the current operations, the improvement options investigated (increasing the recycled content and lightweighting of glass bottles) would improve the overall environmental and economic performance of the supply chain.

10.3 Recommendations for improvements to the beverage industry

Based on the findings of this study, it is recommended that the following be considered by the industry:

i. A life cycle-based approach should be adopted for managing environmental, economic and social performance. This approach would enable beverage producers to develop robust sustainability strategies based on a good understanding of positive and negative sustainability impacts as well as risks and opportunities (in the form of legislation, commodity market pressures, supplier and consumer demands). This approach can also constitute a sound basis for engagement with suppliers, consumers and other actors in the supply chain.

ii. The scope of key environmental performance indicators, which are currently mainly GHG emissions, energy consumption and freshwater consumption should be expanded to include the full range of impacts considered in LCA.

iii. Social impacts of the sector should be measured using appropriate social sustainability indicators, such as the ones developed in this work. These include health impacts and various social risks in supplier-countries.

iv. Appropriate systems should be put in place to facilitate reuse of glass bottles. While this will have economic implications and will necessitate collaboration with retailers and other actors in the supply chain, it has the potential to significantly reduce environmental impacts in the beverage sector.

v. Stringent targets for packaging recycling and increasing the recycled content of packaging should be adopted.

vi. Sourcing of raw materials from sustainable sources should be adopted, taking into account, environmental and social performance of suppliers.

10.4 Recommendations for improvements to UK government

On the basis of this research, the following should be considered by the government:

i. Formulation of policies aimed at performance improvements along the whole supply chain based on life cycle sustainability impacts from the beverage sector.
ii. Expanding the scope of key performance indicators which companies in the UK are required to report on. This should incorporate the full range of impacts considered in LCA as well as social impacts along the whole supply chain.
iii. Encouraging the whole beverage industry to develop a long-term sustainability road map with specific targets for performance improvements.
iv. Educating consumers on the social (particularly health) and environmental consequences of beverage consumption to enable them to make more informed choices as well as drive forward the sustainable consumption agenda.

10.5 Recommendations for future work

On the basis of this research, a number of general recommendations for future work can be made. These recommendations are aimed at improving the methodology and promoting sustainable development in the UK beverage sector. The following should be investigated:

i. The economic, social and socio-economic implications of implementing the improvement options investigated in this work, in terms of legislation, infrastructural requirements, potential costs and revenue for the stakeholders, as well as tradition and consumer behaviour;
ii. Options to introduce alternative and more sustainable types of packaging into beverage sub-sectors in which they are not currently used widely;
iii. Other improvement options which could not be investigated in this work due to data and other limitations, e.g. alternative waste management practices, sustainable procurement strategies, the use of alternative raw materials, and more sustainable transport modes;
iv. Analysis of a greater number of supply chains within each sub-sector and meta LCA analysis to improve confidence in the results of the sectoral analyses;

v. Better quality cost data is required for the economic analysis in order to improve confidence in the results and to assess the economic implications of some of the improvement options considered in this work (e.g. sourcing of agricultural commodities produced from alternative farming systems);

vi. Analysis of sub-sectors not included in this work due to data limitations to provide more accurate estimates of the impacts from the whole beverage sector; and

vii. More in-depth analysis of social impacts along the whole supply chain and integration with environmental and economic aspects.

10.6 Concluding remarks

The current work has attempted to develop an integrated life cycle, systems-based methodology for sustainability assessment in the UK beverage sector. Although the focus of this work is on the beverage sector, the methodology is applicable to other industrial sectors. It is hoped that the findings presented in this work will make a contribution towards sustainable development, not only in the beverage sector, but in industry in general.

APPENDIX 1 LIFE CYCLE ASSESSMENT AND LIFE CYCLE COSTING METHODOLOGY

A1.1 LCA methodology

The LCA methodology is standardised by the ISO 14044 standards (ISO, 2006) and comprises the four key phases: goal and scope definition; inventory analysis; impact assessment; and interpretation (see Figure A-1). The phases of the LCA methodology are detailed below.

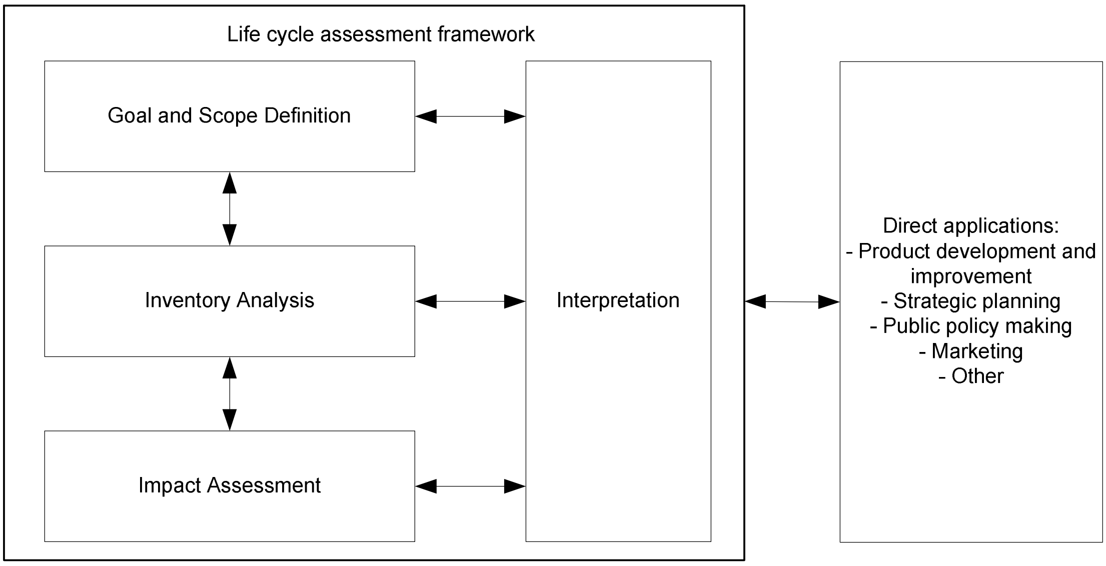

Figure A-1 LCA framework and applications (ISO, 2006)

A1.1.1 Goal and scope definition

The first phase of the LCA methodology involves definition of the purpose, system boundaries, functional unit and assumptions of the study. According to the ISO 14044 standards, the goal definition recommends explicitly stating the intended application, the reason for carrying it out and the intended audience of the study (ISO, 2006). Other critical activities within this phase are definition of the system boundaries (scope definition) and the system function(s), expressed in terms of the *functional unit*. The functional unit expresses the function of the studied product or service in quantitative terms and serves as the basis of calculations (Baumann and Tillman, 2004). It is also crucial for comparative analyses of alternative products or systems.

In this phase, the level of detail and thus data requirements (specific or average data) and the types of environmental impacts to be considered are also defined. The latter determine the parameters for which data will be collected during inventory analysis (Baumann and Tillman, 2004). ISO (2006) also recommends that the inventory parameters and the methodology for the impact assessment should be specified during this phase.

A1.1.2 Inventory analysis

Inventory analysis is the second phase of LCA which involves the compilation and quantification of the environmentally-relevant input and output flows for the system being studied. Environmentally-indifferent flows, for example water vapour, are disregarded when compiling the inventory (Baumann and Tillman, 2004). The inputs include materials and energy used in the system, while the outputs are emissions to air, land and water (Azapagic, 2003). Other key activities carried out during this phase include constructing a flow chart considering the system boundaries defined in the first phase of the methodology, data collection and documentation for all activities in the system, and calculation of the environmental burdens per functional unit. The data used for the quantification of these environmental burdens may be derived from a number of sources including reference publications, direct measurements and databases (Azapagic, 1999; Baumann and Tillman, 2004).

An important methodological problem which may arise during Inventory Analysis is that of allocation. The issue of allocation is a feature of multiple function systems (co-production, recycling and waste management) where environmental burdens need to be allocated among the different functions (Azapagic and Clift, 1990). A considerable body of research has been dedicated to addressing this issue, including Ekvall and Tillman (1997) and Azapagic and Clift (1999). It is important to note that the basis chosen for allocation (for example physical relationships or economic value) can greatly influence the results of an LCA study. This is demonstrated in the case study of Scotch whisky (see Chapter 8). Therefore, the ISO 14044 standards (ISO, 2006) recommend the following hierarchy of procedures for dealing with allocation issues in LCA:

i. where possible, allocation should be avoided by increasing the level of detail of the model or expansion of the system being studied;

ii. where allocation cannot be avoided, the environmental burdens should be partitioned between the different functions based on the underlying physical relationships; and
iii. where allocation cannot be carried out based on physical relationships, it may be carried out based on other relationships such as economic value of the products.

A1.1.3 Impact assessment

The life cycle impact assessment (LCIA) phase involves the aggregation of data determined in the inventory analysis into environmental impact categories including global warming, acidification, eutrophication and eco-toxicological impacts (Azapagic, 2003). The key aim of LCIA is to translate the inventory data into more environmentally-relevant information, i.e. information on impacts on the environment (Baumann and Tillman, 2004). According to ISO 14044, LCIA consists of four main stages: Classification, Characterisation, Normalisation and Valuation, where the latter two stages are optional.

Classification refers to the sorting of the inventory result parameters and their assignment to various impact categories to which they contribute (Azapagic, 1999; Baumann and Tillman, 2004). For example, chlorofluorocarbons (CFCs) contribute to global warming as well as to ozone layer depletion.

Characterisation is a quantitative step which involves multiplication of the burdens determined in the inventory phase by a ‘characterisation’ or ‘potency’ factor to determine the contribution of each burden to the appropriate impact category. For example, all emissions which contribute to global warming (CO_2, CH_4, N_2O, etc.) are multiplied by their characterisation factors and added up, resulting in a quantitative estimation of the global warming impact (Baumann and Tillman, 2004).

In the Normalisation phase, the characterised results are related to (divided by) the actual (or predicted) magnitude for each impact category (Baumann and Tillman, 2004). This facilitates a better understanding of the relative significance of the environmental impacts caused by the studied system. However, care is required when interpreting normalised results as the results of the system under study are presented in relation to regional impacts which may be uncertain.

Valuation, also referred to as 'weighting' of impacts, is defined as "the qualitative or quantitative procedure where the relative importance of an environmental impact is weighted against all other" (Baumann and Tillman, 2004). This implies that all the impacts are expressed as a single impact function which represents a measure of the environmental performance of the system. Weighting may be deemed necessary when trade-offs occur in LCA studies aimed at comparing alternative product systems (EC, 2010). Due to the subjective nature of this stage, several techniques including impacts analysis matrix, cost benefit analysis and analytical hierarchy process have been suggested as useful for this evaluation (Azapagic et al., 2003).

Impact assessment methods are generally classified into problem-oriented (midpoint) and damage-oriented (endpoint) based on where the impacts occur. In the former, the burdens are aggregated based on their potential contribution to environmental consequences, while the latter approach models the actual damage of environmental interventions on various components of the ecosystem for example, impacts on human health, the natural environment and natural resources (see Figure A-2).

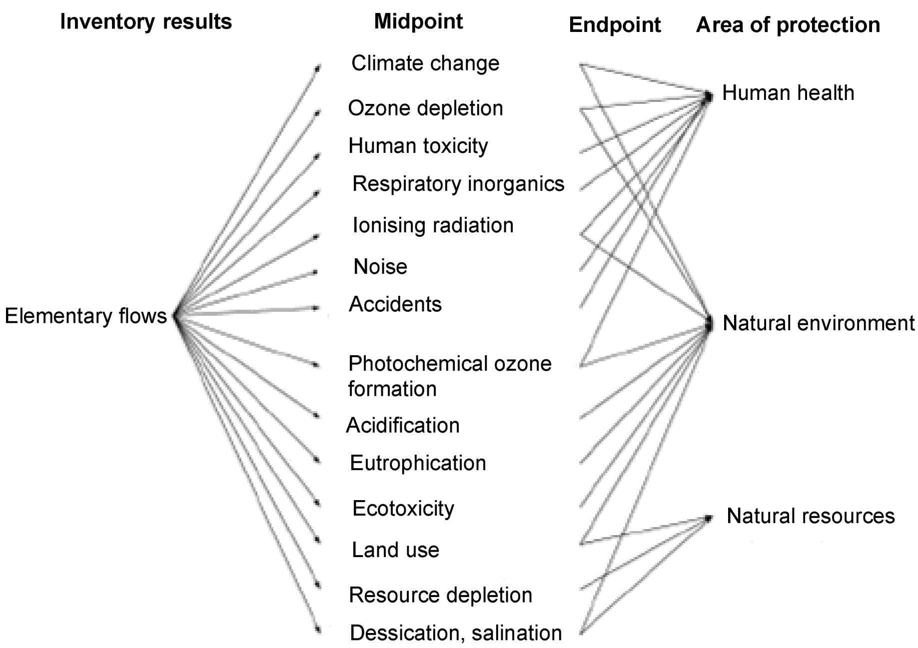

Figure A-2 Framework of impact categories for characterisation modelling at midpoint and endpoint levels (EC, 2010)

Examples of midpoint approaches include the CML 2001 method (Guinée et al., 2001), Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts (TRACI) (Bare et al., 2003) and Environmental Development of Industrial Products (EDIP) methods (LCA Centre, 2003), while the Ecoindicator (Pré Consultants, 2000) is an example of the endpoint approach.

A1.1.4 Interpretation

The primary aim of this final phase of the LCA study is the utilisation of results obtained during the preceding phases to meet specified goals. In addition to system modifications to improve its performance, interpretation covers identification of hot spots within the life cycle, sensitivity analysis, as well as final conclusions of the LCA study. The LCA is carried out as an iterative process where each step may be revisited as the need arises. On completion of the assessment, the questions raised during the goal and scope should have been answered adequately (Hauschild et al., 2005).

A1.2 LCC methodology

The LCC methodology is seen as complementary to LCA. Its general framework is therefore defined in line with the ISO 14040/44 LCA standards and consists of the following phases (Swarr et al., 2011): Goal and scope definition, Economic life cycle inventory, Interpretation, and Review and reporting. It is pertinent to note that the guidelines for this methodology allow a measure of flexibility to adapt these components depending on specific requirements of the study being carried out. However, a key guiding principle is that the rigour of the analysis and the extent of independent review should be in line with the defined goal and scope (Swarr et al., 2011). The key activities carried out within these phases are described below.

A1.2.1 Goal and scope definition

Similar to the LCA methodology, goal and scope definition in LCC involves defining the goal of the study, the intended application and audience, the system boundaries and the system function expressed in terms of the functional unit. However, certain elements of LCC diverge from LCA. For example, goal and scope definition in LCC requires specifying from whose perspective (e.g. producer, consumer) the cost assessment is carried out (Swarr et al., 2011). This arises from the fact that the actors in the product supply chain view the costs from different perspectives, values and sometimes conflicting goals. Although the results of the analysis will be presented from the perspective of one stakeholder or supply chain actor, it will ideally be structured to inform all stakeholders (Swarr et al., 2011). Furthermore, the code of practice requires that where the LCC forms part of a sustainability assessment with a corresponding LCA, the goal and scope definitions for both assessments must be compatible (Swarr et al., 2011).

Identifying the type of costs (e.g. internal and external costs) is crucial for accurately estimating the LCC of the supply chain. Swarr et al. (2011) categorise internal costs as those borne by actors directly involved in the supply chain (e.g. manufacturer, transporter and consumer). Internal costs, which can be considered as business expenses, include those for production of raw materials, packaging materials and utilities, freight, as well as waste management (disposal, recycling and wastewater treatment of in-process and post-consumer waste). External costs, on the other hand, are borne by actors not directly involved in the supply chain for example, fees for municipal waste recovery and indirect health costs (Swarr et al., 2011).

A1.2.2 Economic life cycle inventory

The economic LCI phase is comparable to that of the LCA and will often build on the LCI of material and energy flows specified in the LCA of the product system (Swarr et al., 2011). The code of practice for LCC also specifies that the cost inventory should be built on "a well-defined cost classification system that is valid and commonly understood across all actors and organisations within the defined system boundaries". Common issues which arise in this phase include (Swarr et al., 2011):

- data (availability, quality and uncertainty);
- volatile prices;
- time-dependent value of money; and
- allocation.

Data issues in LCC mainly relate to availability, quality and uncertainty. Cost data may be obtained from diverse sources including company-specific costs in the supply chain, generic databases, published price data and spot market prices. Company-specific cost data are normally confidential and difficult to obtain. Data from generic databases and market prices, on the other hand, are more readily available. However, generic data are normally available as estimates which may not accurately reflect the system being studied.

Another critical issue encountered during this phase of the assessment is that of the volatile nature of costs and cost-influencing parameters (Swarr et al. 2011), which may be subject to external forces. An example is that of agricultural commodity prices which may be affected by factors such as political and economic events, the weather, currency exchange rates, etc. Swarr et al. (2011) observe that this could lead to systemic errors in the analysis. The issue of currency exchange rates is particularly crucial for the current study due to the global nature of the systems studied – different components of the supply chains are located in different geographic regions with different currencies.

In addition to the above-mentioned, another critical issue relates to the time value of the money flows in the LCC analysis – cost data for a particular analysis may be collected over a period of time and may not accurately reflect the 'present' value. Furthermore, this presents a challenge for the accurate integration of environmental and economic impacts because LCA models are traditionally 'steady-state' or time invariant. Swarr et al. (2011) however, recommend the selection of an appropriate discount rate depending on the perspective of the supply chain actor, for converting future costs to a 'present' value. However, the decision as to whether discounting is required for a particular study or the discount rate chosen, are dependent on the goal and scope of the study (Swarr et al., 2011). Furthermore, the code of practice allows for discounting to be neglected if the duration of the system under study is less than 2 years. It is pertinent to note, however, that the LCC is not intended as a substitute for detailed cost accounting tools used in organisations. Rather, it is aimed at helping to identify economic 'hot spots' in the supply chain which can be further investigated using more robust financial accounting methods and tools.

The issue of allocation of impacts among multiple system functions is also critical in LCC. This presents a challenge when the LCC is conducted with a complementary LCA due to the need for a fair and accurate method for allocating costs and environmental impacts among the different system functions. Particular care is required when handling allocation in LCC and corresponding LCA studies due to the fact that the ISO 14040/44 guidelines for allocation in LCA are not consistent with standard practice in management accounting (Swarr et al., 2011). Furthermore, due to the fact that allocation and system expansion affect the system boundary, care is required in order to maintain consistent system boundaries between the LCA and corresponding LCC (Swarr et al., 2011). Where allocation issues arise in the current study (e.g. co-production in the Scotch whisky system – see Chapter 9), the impacts from generation of the co-products have been allocated by subtracting the final cost of the co-products from the total life cycle costs. This is similar, in principle, to the system expansion and avoided burden approach in LCA.

A1.2.3 Interpretation

In LCA, interpretation can be described as a systematic procedure to identify, qualify, check and evaluate information obtained from the LCI and/or LCIA results and the presentation of this information in accordance with the goal and scope of the study (ISO, 2006). This definition can be applied to LCC by substituting "LCI and/or LCIA" with "cost accounting" (Rebitzer, 2005). The interpretation phase in LCC is crucial due to the fact that it provides a relevant and fair appreciation of the work carried out as well as recommendations for the future (Swarr et al., 2011). In studies where the assumptions and methodological choices may exert a significant influence on the results, the interpretation phase is all the more critical. The code of practice for LCC recommends that interpretation in LCC should include identification of significant issues (hot spots), evaluation and conclusions (including recommendations and adequacy of reporting). Similar to LCA, the interpretation phase in LCC also involves checks of completeness and consistency, as well as uncertainty and sensitivity analysis.

Consistency and completeness checks in LCC mainly relate to ensuring that the rules governing temporal and geographical differences and issues have been applied consistently. Furthermore, any factors which may exert a significant impact on the interpretation of the results and on the conclusions of the study should be examined in detail and discussed (Swarr et al., 2011). Uncertainty analysis focuses on data which may be subject to factors such as coarse assumptions, time-dependent variations or value choices, while sensitivity analysis involves a quantitative examination of how sensitive the LCC results are to variations in the input data due to the range of assumptions involved in the study (Swarr et al., 2011).

A1.2.4 Review and reporting

The guidelines governing critical review in LCC are based on the ISO 14040/44 standards. This process, which is deemed mandatory if the results of the analysis are intended to be made public, enhances the quality and credibility of the analysis by ensuring that the following requirements are fulfilled (Swarr et al., 2011):

- the goals of the study should be sufficiently comprehensive to validate the conclusions;
- the methods used for the analysis should be scientifically and technically valid;
- the data used for the analysis should be appropriate and reasonable in relation to the scope;
- interpretation of the results should reflect the defined goals, as well as limitations of the study;
- sensitivity analyses on the input data and assumptions should be carried out;
- discounting should be carried out appropriately;
- communication of the results should represent the totality of the data;
- original cost data should be presented for comparative product assertions; and
- the study report should be transparent and consistent.

Appendices 2, 3 and 4 are presented in the compact disc attached at the end of this work, while subsequent sections detail the contents of Appendices 2, 3 and 4.

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APPENDIX 2 RELATIVE ENVIRONMENTAL BURDENS

Appendix 2 provides a detailed assessment of the environmental burdens for different categories of impacts considered in the LCA case studies: Carbonated soft drinks, beer, wine, bottled water and Scotch whisky. The relative environmental burdens are shown for the different types of packaging used in the UK market for the different types of beverages. As mentioned earlier, the impact assessment has been carried out using the CML 2001 problem-oriented method. The sub-sections within Appendix 2 are given as follows:

i. Appendix A2.1: Carbonated soft drink LCA Burdens
    a. Carbonated soft drink Glass bottle (0.75 l)
    b. Carbonated soft drink Aluminium can (0.33 l)
    c. Carbonated soft drink PET bottle (0.5 l)
    d. Carbonated soft drink PET bottle (2 l)
ii. Appendix A2.2: Beer (Lager) LCA Burdens
    a. Beer (Lager) Glass bottle (0.33 l)
    b. Beer (Lager) Aluminium can (0.5 l)
    c. Beer (Lager) Steel can (0.5 l)
iii. Appendix A2.3: Red wine LCA Burdens
    a. Red wine Glass bottle (0.75 l)
iv. Appendix A2.4: Bottled water LCA Burdens
    a. Bottled water Glass bottle (0.75 l)
    b. Bottled water PET bottle (0.5 l)
    c. Bottled water PET bottle (2 l)
v. Appendix A2.5: Scotch whisky LCA Burdens
    a. Scotch whisky Glass bottle (0.70 l)

APPENDIX 3 DATA QUALITY ASSESSMENT FOR THE LCA

Appendix 3 provides a detailed data quality assessment of the LCA for the different types of beverages considered in this study: Carbonated soft drinks, beer, wine, bottled water and Scotch whisky. The data quality assessment is shown for the different types of packaging used in the UK market. The sub-sections within Appendix 3 are given as follows:

i. Appendix A3.1: Carbonated soft drink LCA Data Quality Assessment
   a. Carbonated soft drink Glass bottle (0.75 l)
   b. Carbonated soft drink Aluminium can (0.33 l)
   c. Carbonated soft drink PET bottle (0.5 l)
   d. Carbonated soft drink PET bottle (2 l)

ii. Appendix A3.2: Beer (Lager) LCA Data Quality Assessment
   a. Beer (Lager) Glass bottle (0.33 l)
   b. Beer (Lager) Aluminium can (0.5 l)
   c. Beer (Lager) Steel can (0.5 l)

iii. Appendix A3.3: Red wine LCA Data Quality Assessment
   a. Red wine Glass bottle (0.75 l)

iv. Appendix A3.4: Bottled water LCA Data Quality Assessment
   a. Bottled water Glass bottle (0.75 l)
   b. Bottled water PET bottle (0.5 l)
   c. Bottled water PET bottle (2 l)

v. Appendix A3.5: Scotch whisky LCA Data Quality Assessment
   a. Scotch whisky Glass bottle (0.70 l)

APPENDIX 4 DATA QUALITY ASSESSMENT FOR THE LCC

Appendix 4 provides a detailed data quality assessment of the LCC for the different types of beverages considered in this study: Carbonated soft drinks, beer, wine, bottled water and Scotch whisky. The data quality assessment is shown for the different types of packaging used in the UK market. The sub-sections within Appendix 4 are given as follows:

i. Appendix A4.1: Carbonated soft drink LCC Data Quality Assessment
    a. Carbonated soft drink Glass bottle (0.75 l)
    b. Carbonated soft drink Aluminium can (0.33 l)
    c. Carbonated soft drink PET bottle (0.5 l)
    d. Carbonated soft drink PET bottle (2 l)
ii. Appendix A4.2: Beer (Lager) LCC Data Quality Assessment
    a. Beer (Lager) Glass bottle (0.33 l)
    b. Beer (Lager) Aluminium can (0.5 l)
    c. Beer (Lager) Steel can (0.5 l)
iii. Appendix A4.3: Red wine LCC Data Quality Assessment
    a. Red wine Glass bottle (0.75 l)
iv. Appendix A4.4: Bottled water LCC Data Quality Assessment
    a. Bottled water Glass bottle (0.75 l)
    b. Bottled water PET bottle (0.5 l)
    c. Bottled water PET bottle (2 l)
v. Appendix A4.5: Scotch whisky LCC Data Quality Assessment
    a. Scotch whisky Glass bottle (0.70 l)