The University Of Sheffield.

AN INVESTIGATION INTO THE DRIVERS, BARRIERS AND POLICY IMPLICATIONS OF CIRCULAR ECONOMY USING A MIXED-MODE RESEARCH APPROACH

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Declaration

This PhD thesis is my own original work and has not been submitted elsewhere in fulfilment of this or any other award.

Abstract

The 21st century presents a new set of challenges to mankind, notably intensive global competition, increasing greenhouse gas emissions and rapid growth in population relying on a resource base that is finite in nature. Addressing these challenges has therefore become a matter of global concern and urgency, prompting government industries and the financial markets to rethink their approaches with the view to move towards a low-carbon economy. The move towards a circular economy which presents a shift from the current produce-use-dispose approach is touted as a practical solution to the planet's emerging resource crunch given its potential to address both environmental and socio-economic issues. However, despite the promising nature of the circular economy paradigm, a lack of understanding of the concept is rendering its acceptance and implementation a difficult proposition. This is further compounded by lack of genuine interest from key stakeholders regarding the concept, given that a shift to a circular economy would require considerable changes in all parts of the value chain. At present, relevant stakeholders are scrambling for an efficient, consistent and reliable approach towards understanding the concept for onward implementation. In pursuit of a system of operation that satisfies the dual role of GHG mitigation and wealth generation, the current research presents a rigorous analysis of the concept of circular economy with the view to shed light on its drivers, barriers and policy implications. This was carried out using two approaches. The first approach entails an exhaustive examination of the supply chain of representative metals that have primary and secondary routes of production through using environmental lifecycle assessment framework. For the four case studies considered, the competitive edge of the circular economy paradigm over the linear approach was demonstrated, at least from a purely environmental perspective. Building upon the LCA study, the current work examines the barriers and drivers towards circular economy practices implementation. Set against a background of stakeholder engagement, key stakeholders from the metals supply chains were identified (including scrap dealers, public authorities, consumers, manufacturers, recyclers, civil society) and interviewed with the view to provide qualitative empirical evidence of the feasibility of such transition. Thematic content analysis of the interviews with key actors and stakeholders yielded seven themes and several sub-themes which can shape the understanding and facilitate the transitioning from a linear economy to circular economy, whilst laying a solid foundation for its acceptance and future implementation. Overall, the analysis

presented in this work highlight the competitive edge of circular economy, however, a key concern is that the economic viability of such transition may be questionable given that mechanisms to endorse them are deemed weak at the moment. For a move to circular economy to become a reality, concerted effort from all stakeholders including policy makers, energy professionals and the society at large is required.

Dedication

To my parents, who have always supported me and given me unconditional love.
To my late grandfather Shaikh Abubakar Mahmoud, who sadly never lived long enough to see me achieve anything but always believed in me, encouraged and prayed for me.

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Abbreviations and acronyms used in this thesis

AP-Acidification Potential

CE- Circular economy

EIO-Environmental input-output

EMA-The Ellen MacArthur foundation

EP-Eutrophication Potential

EU-European Union

FAETP-Fresh Water Aquatic Ecotoxicity

GWP-Global Warming Potential

HTP- Human Toxicity

ISO-International Organisation for Standardisation

LCA-Life cycle assessment

LCIA-Life Cycle Impact Assessment

LCI-Life Cycle Inventory analysis

MAETP-Marine Aquatic Ecotoxicity

ODP-Ozone Layer Depletion

ONS-Office for National Statistics

POCP- Photochemical Oxidation

SETAC-Society for Environmental Toxicology and Chemistry

SND-The Suzhou New District

TAETP-Terrestrial Ecotoxicity

UK-United Kingdom

UNEP- United National Environment Programme

UPR-Unit process exchanges

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Chapter one: Introduction

1.1 Background

For years, the issue of climate change couple with the resultant global warming and the fight to reverse it was seen by some as the ideological shibboleth of neo-liberal scientists. Today, concerted efforts of researchers across the globe and the Intergovernmental Panel on Climate Change's report have established clear connections between the amount of anthropogenic greenhouse gas (GHG) emissions and the global surface temperature increase from preindustrial levels (IPCC, 2015). The issue of climate change has led to irreversible rise in sea level and the consequent submersion of low lying areas, fierce competition for natural resources, a decline in economic activities and rural-urban migration, amongst others (IPCC, 2007a; Rockström et al., 2009). The societal impacts of these changes are also likely to be severe if left uncontrolled. Informed by this compelling scientific evidences, the Paris Agreement – which despite President Trump's ill-timed decision to reverse an earlier decision by the United States, is still supported by numerous countries that attended the 2015 United Nations COP21 Summit (Bodansky, 2016; Bodle et al., 2016; Dimitrov, 2016; Doelle, 2016; Morgan, 2016). Accordingly, every member country has set targets to reduce GHG emissions with the view to ensure that the expected rise in temperature by 2100 is kept below 2 °C. Achieving this aim will require more than setting targets for emissions reduction, as such, a swift transition to a low-carbon economy, backed by effective policy instruments is paramount.

Indeed, increasing GHG emissions, intensive global competition and a fast growing population utilising finite resource base has presented mankind with a new set of challenges (Allen, 2016). The extraction of materials and ores/industrial minerals from 1900 to 2005 rose by a factor of 8 and 27 respectively (UNEP, 2010). Such level of extraction alongside the processing and utilisation of the ensuing raw materials are contributing to the overall quality of life of billions of people through, for example, construction of safer homes, development of reliable transportation systems, efficient information and communication networks, production of cleaner water and lots more (Ayres et al., 2004; Department of Trade and Industry, 2006). Yet the environmental burden associated with the aforementioned benefits is enormous and bound to increase as the population of the world increases in number and wealth (Lutz et al., 2001). The demand for natural resources continues to increase, leading to a corresponding increase of material footprints of nations (Wiedmann et al., 2015). At the same time, The World Bank estimates global solid waste at 1.3 billion tonnes per year and is forecasted to increase to nearly 2.2 billion tonnes per year by 2025 (Hoornweg and Bhada-Tata, 2012). Although these estimates are laced with uncertainty, they nevertheless provide useful insights regarding one of the major challenges that confront mankind: how do we address the harmful effects that pertains to the unprecedented consumption of natural resources, whilst minimising waste? Concern over these issues are no longer confined to the isolated environmental activist or advocates of green consumption. Government, industries, companies as well as financial markets are all rethinking their approaches to industrial activity by taking into consideration the entire life cycle environmental impact.

Every step in the life cycle of a process, activity, or even services leaves a footprint on our planet. From the raw materials extraction to material processing and manufacturing for onward conversion into familiar products, through to the application or use of such products to their final disposal, each phase must be managed in a responsible way in order to prevent the risks associated with the depletion of resources, increase in GHG emissions and waste accumulation (Hellweg and i Canals, 2014). Due to their large consumption across the globe, the environmental impact of some materials, notably metals, are particularly critical. Metals are obtained from the earth crust and have been widely used by mankind since ancient ages due to their strength, durability and high resistance to natural wear and tear (Halada et al., 2008). In the past, metals were mainly used for cooking, farming tools, locomotive wagons and weapons, but due to advancement in technology (e.g. combination of different metals to form alloys), the horizons of their application has widened enormously. Currently, almost any object produced with the aid of technology uses metals in one form or other, making their use in our daily life to become inevitable.

The metal sector is a heavy industrial sector which received a special attention towards global decarbonisation efforts in the recently published Intergovernmental Panel on Climate Change Fifth Assessment Report (IPCC, 2014). Much of the economic growth witnessed by emerging markets today is triggered by expansions in manufacturing and construction activities that requires greater metal inputs, resulting in overall increase in the GHG emissions of the sector (Sustainability Accounting Standards Board, 2014). However, the rates at which metals are recycled have increased and the advent of new and advanced technologies has further reduced the need to extract virgin materials, thereby decreasing the environmental burden of these commodities (Koh et al., 2016). As illustrated in Figure 1, technology-based options including the use of cleaner and efficient production processes, end of pipe treatment and efficient waste management and recovery systems have all contributed to the overall improvement in emissions intensity within the sector (Koh et al., 2016). Given these profile of the metal industry in terms of its potential to contribute towards decarbonisation efforts, it is therefore selected as the main focus of the current work.

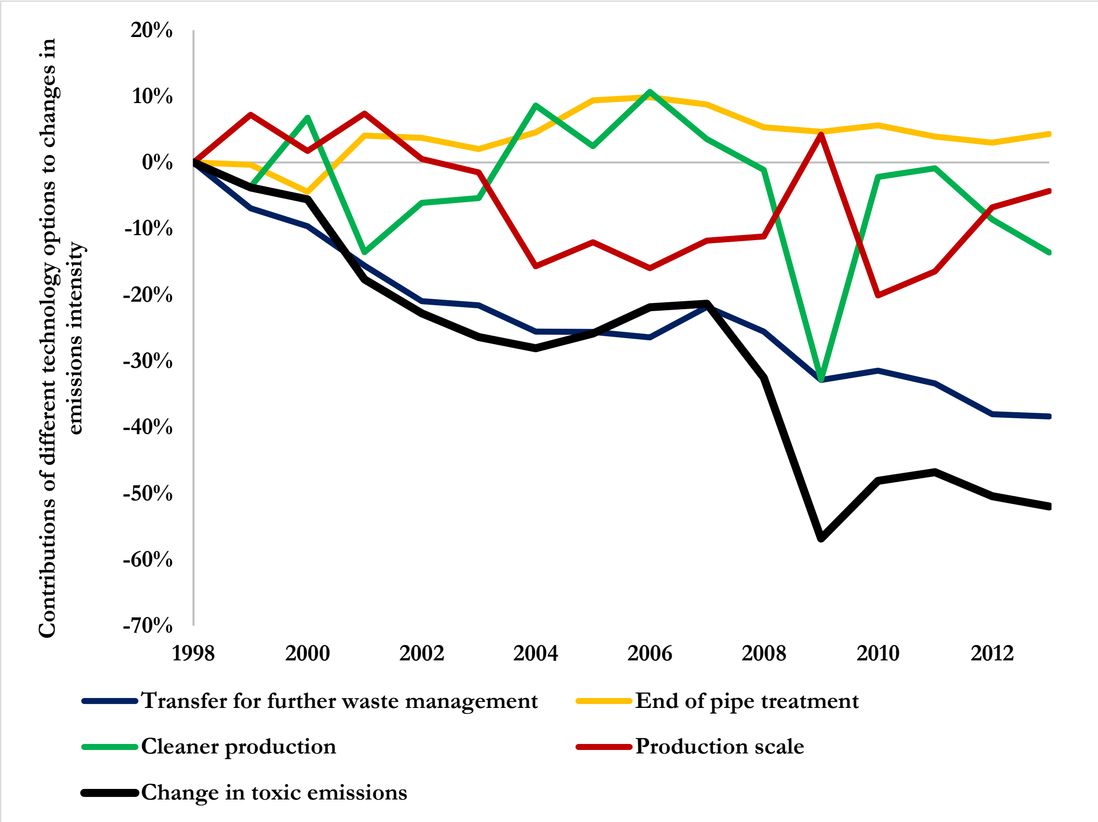

Figure 1.1: Contributions of four categories of mitigation options to reductions in toxic emissions intensity in the US across the metal and fabricated metal sector (Koh et al., 2016).

Concerns about the "health" of our planet necessitate a careful evaluation of the environmental impact of our activities. Reserves of fundamental resources including rare earth metals and essential minerals are declining with a corresponding increase in cost of exploration and extraction activities. As the impact on the natural environment continue to rise due to the influence of such activities, the need for the identification and quantification of the underlying upstream causes of these impacts with the view to developing lasting solutions to ensure a sustainable development of the planet has become important (Koh et al., 2013). Life cycle assessment (LCA) is a time-tested computational tool that can assist with the identification of sustainable pathways through the consideration of the burdens of materials both during manufacturing and as a product (Hellweg and i Canals, 2014). Current application of LCA are mainly focused on the evaluation of the complete environmental impact of a material or product from a number of phases including the raw materials extraction, materials processing, application, and final disposal. This mode of tracking the environmental impact of production and consumption pattern is often termed the linear economy/consumption model given that it is generally characterised by the extraction of resources for production and consumption on a one-way track with no policy for reuse or active regeneration of the natural system (McKinsey, 2012). The approach is deemed wasteful both in terms of resources and financial cost and it exerts undue pressure on the environment (EU, 2014). For instance, Girling (2011) reported that 90% of the raw materials used in manufacturing become waste prior to the final product leaving the production plant while 80% of products manufactured are disposed of within the first six months of their life. This, alongside the ballooning tensions regarding geopolitics and supply risk, are contributing to volatile commodity prices (Ku and Hung, 2014; Moran et al., 2015). At present different strategies and plans are still being proposed and implemented in response to resource limitations, population pressure and general environmental damage caused by current consumption patterns (McKinsey, 2012).

The circular economy CE (Figure 1.2) presents a shift from the linear model and is touted as a practical solution to the planet's emerging resource crunch given its capability to assist in stabilising some of the aforementioned issues through the decoupling of economic growth from resource consumption (Genovese et al., 2017). The concept has the potential to address both environmental and socio-economic issues (Witjes and Lozano, 2016). It is a strategy to facilitate economic growth and at the same time minimise resource use by closing all resource loops and reconnecting them at various nodes, thus reducing and ultimately eliminating waste (McKinsey & Company 2013). Circular economy represents a theoretical concept targeted at creating an industrial system that is restorative by intention (Seuring and Müller, 2008; Srivastava, 2007) and can be seen as an extension of closed-loop supply chains (Genovese et al., 2017). It aims at transforming waste into resources and on bridging production and consumption activities (Witjes and Lozano, 2016). A circular economy "closes 'resource loops' in all economic activities in a sense that there is no 'end' within a circular economy, but a 'reconnection to the top of the chain and to various activity nodes in between" (Hislop and Hill, 2011). It promotes economic production systems that are connected with end treatment systems through reusing and recycling systems, thereby culminating in a closed loop of materials and energy flows. The concept of circular economy entails for more than just recycling as detailed in Figure 1.2 where recycling is depicted as an "outer circle" which requires more energy than the "inner circles" of refurbish, reuse and remanufacture.

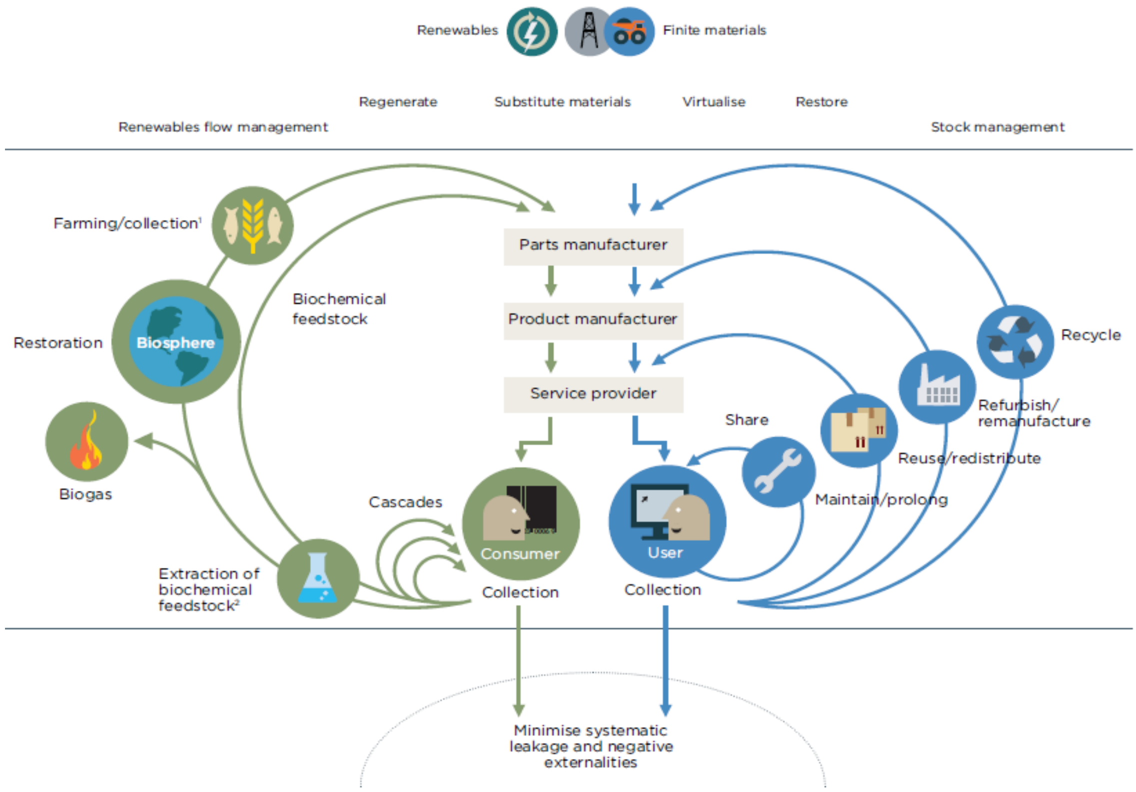

Figure 1.2: Circular economy – an industrial system that is restorative by design (Source: Ellen MacArthur Foundation, 2013)

In their work, McDonough and Braungart (2010) reported that circular economy extends the boundaries of environmental sustainability given that it emphasises the transformation of product in a manner that a workable interaction between economic growth and ecological systems to be established (Francas and Minner, 2009). This is made possible through the creation of a paradigm shift in the restructuring the pattern of material flows driven by long-term economic growth and innovation (Braungart et al., 2007). Circular economy is not just confined to reuse or recycling of resources, it centres on a restorative industrial system targeted towards designing out waste (Tukker, 2015). Accordingly, the goal within the concept of circular economy is not design only for improved end-of-life recovery or for the reduction of the use of the environment as an outlet for residuals (Andersen, 2007), it entails the creation of systems that allow for production mechanisms that are self-sustaining, minimise energy and material use, true to nature and in which materials can be put into use in a cyclic and repetitive manner (McDonough and Braungart, 2010; Preston, 2012; Stahel, 2016). We live in a world interlinked by product supply chains that are networked, multidimensional production technologies, and consumption patterns that are nonlinear (Acquaye et al., 2017; Koh et al., 2016). As such, finding ways to align environmentally sustainable supply chain strategies to address environmental challenges of material and energy use is important if the boundaries of environmental sustainability guided by the principles of circular economy are to be extended.

In spite of the assurances and advantages offered by circular economy in terms of its ability to transform waste into resources whilst bridging the gap between production and consumption activities, the embrace of the concept into the mainstream of decision making is still a difficult proposition. This is further compounded by lack of genuine interest from key stakeholders regarding the concept, given that a shift to a circular economy would require considerable changes in all parts of the value chain whilst affecting all stakeholders including policy makers, managers, production and design engineers, energy and sustainability managers, environmentalist and the society at large. The relevant stakeholders are still scrambling for an efficient, consistent and reliable technological know-how towards gaining full understanding and appreciation of the circular economy.

In pursuit of a system of operation that satisfies the dual role of GHG mitigation and wealth generation, an assessment of the CE paradigm with subtle indigenous understanding is crucial to a successful implementation of the concept towards a sustainable economy. Against this backdrop, current work seeks to explore the principles of circular economy with the view shed light on the underlying factors as to why its overall acceptance and embrace into mainstream production protocols is still limited despite the huge opportunities it offers. This will be achieved through a thorough examination of the supply chain of some selected metals that have primary and secondary routes of production through the lens of environmental lifecycle assessment framework within a circular economy paradigm. Given that key stakeholders are an integral part of the shift towards circular economy, the current work will augment findings from supply chain implications of circular economy transition by conducting interviews to provide qualitative empirical evidence of the feasibility of such transition. In doing so, it is intended that the current work will contribute both quantitatively and qualitatively towards the understanding and embrace of circulation economy, whilst laying the foundation for its implementation.

1.2 Project aim and specific objectives

The central aim of this work is to investigate the environmental implications of circular production systems across a number of sustainability metrics in comparison to the traditional linear production paradigm using key representative metals as case studies, with the view to identify the drivers, barriers, market dynamics and policy implications of the transition towards a circular economy. To achieve this aim, the following specific objectives have been formulated as indicated below:

- Carry out a detailed review of the concept of circular economy to identify the drivers, barriers and policy implications, in terms of the challenges they constitute towards the implementation of circular production systems
- To establish the competitive edge which the circular economy paradigm offers in comparison to linear economy, using the supply chain of some selected metals that have well-established primary and secondary production routes as case studies, through the lens of environmental lifecycle assessment framework, across a number of sustainability metrics
- To generate themes or dimensions that will shape the understanding and facilitate the transitioning from a linear economy to circular economy through thematic content analysis of interviews with key actors and stakeholders, whilst establishing a robust qualitative empirical evidence of the feasibility of such transition
- To integrate findings from the quantitative analysis based on life cycle assessment of metals and the qualitative analysis derived through stakeholder engagement and interviews, with the view to gain a better understanding of the transition towards a circular economy and lay a solid foundation for its acceptance and implementation

1.3 Key research gaps identified

A summary of key research gaps which led to the formulation of the research questions (highlighted in Chapter three, Section 3.2) and the set of research objectives highlighted above is provided in this section. A considerable amount of research on circular economy at the regional and industrial-park levels have been carried and follow top-down approaches in their implementation. However, there is a dearth of research that explores how local firms and stakeholders interact and participate in a circular economy within a specific sector. Given the unique role of these key actors towards transitioning to a circular economy, it is important to explore their views using bottom-up approaches which takes into account environmental, economic and policy considerations.

In the realm of circular economy research, there is a form of geographical imbalance with countries like China taking leadership role as part of efforts towards their national development plans and strategies. In the UK and EU for example, circular economy is largely seen as a strategy for implementation of environmental policies and waste management, although this notion is gradually changing. In order to reinforce and shape the understanding of key stakeholders (consumers and producers) within the EU and UK in particular, it is important to gain an understanding of the underlying drivers of the circular economy paradigm using a specific industrial sector with the view to highlight its unique importance and attributes. Furthermore, the socio-political implication of transitioning from linear economy to circular economy in the context of the UK using specific sector such as the metals sector has not been fully explored. This is an important gap to fill given its potential to aid the identification and classification of different drivers of, and barriers to, a circular supply chain, at a local level based on different perspectives from key stakeholders (Matthews and Tan, 2011).

Additionally, despite the surge in interest from academics and practitioners on CE, there is limited work which compares the linear and circular systems using case studies specific to a given sector. In order to enable a circular economy paradigm, shift at firm level, it is important to understand supply chains and their life cycle assessment to properly compare different options that can be implemented within a circular economy process. This has the potential of widening empirical evidences to illustrate the competitive edge of circular economy over linear economy. It is intended that if these aforementioned issues are addressed, it will go a long way in shaping the understanding of key concepts towards transitioning from linear economy to a circular economy. Further details of the gaps in knowledge identified is provided in Section 2.12, Chapter two.

1.4 Thesis structure and organisation

As highlighted in the preceding sections, this chapter provides a broad overview of the focus of the current research detailing its background and the aim and specific objectives. The remaining chapters of the thesis are structured as follows.

In Chapter 2, a review of the extant literature relevant to the current work is provided. It consists of both academic and wider literature relevant to the aim and specific objectives of this research. The chapter discusses the concept of circular economy in terms of its origins, implementation based on supply chain research and identifies the research gaps which the current work seeks to fill.

Chapter 3 provides an overview of the research methods, paradigms and approaches that have helped to shape the research design which the current work adopts. The chapter provides justification of the selection of an appropriate research approach in the development of two in-depth, related studies, including quantitative analysis of linear and circular supply chains using LCA framework and semi-structured interviews with multiple stakeholders within the metals supply chain.

In Chapter 4, results of the comparative analysis of linear economy versus circular economy based environmental lifecycle assessment framework, across a number of sustainability metrics is metrics. The primary focus of this in-depth applied case study is to identify whether the circular supply chains of the metals, which are produced from recycled materials, exhibits lower environmental impacts compared to those produced through a traditional linear supply chain from virgin raw materials.

Chapter 5 presents the analysis and findings from the qualitative aspects of this research. Building upon the findings from the comparative LCA study, the chapter details an analysis of the interviews from key stakeholders with a focus on the drivers and barriers of implementing circular economy approaches within the metals industry.

Finally, in Chapter 6 an overview of the key conclusions of this research, contributions to both theoretical literature and management practice, limitations of the research and directions for future work is presented.

Chapter Two: Literature Review

This chapter presents an exploration of both the academic and wider literature relevant to the aims and objectives of this research. It begins with a brief background to the field of circular economy generally, before moving on to assess some of the key themes under which circular economy research has been focusing upon. The chapter therefore creates a link between what has already been studied and what the present research investigates; and identifies current gaps in knowledge that this research seeks to fill.

2.1 Circular economy

The current mode of production and consumption (produce-use-dispose) often termed as linear economy/consumption model is characterised by the extraction of resources for production and consumption on a one-way track with no policy for reuse or active regeneration of the natural system (McKinsey, 2012). It is seen as wasteful both in terms of resources and money and puts undue pressure on the environment (EU, 2014). Various strategies and plans have and are still being proposed and implemented in reaction to resource limitations, population pressure and general environmental damage caused by current consumption patterns. The circular economy paradigm offers a shift from this linear model. It is a strategy to facilitate economic growth and at the same time minimise resource use by closing all resource loops and reconnecting them at various nodes, thus reducing and ultimately eliminating waste (McKinsey & Company 2013).

A lot of authors regularly attribute the concept of circular economy to American economist Kenneth Boulding (Hu et al, 2011); it is similarly argued that the concept of circular economy can be traced to Pearce and Turner (1990). The roots of circular economy can also be traced back to the industrial ecology movement. It is evident that the circular economy concept cannot be traced to a single field of study or author. The origins will be discussed in more detail in the following sections. Today, circular economy signifies a development strategy that assists economic growth while optimising consumption of resources. The aim is a total transformation of production chains and consumption patterns, and the redesign of industrial systems at the system level (Ellen MacArthur Foundation, 2012). The implementation of circular economy and its principles entails a transformation of production and consumption chains and patterns to create a new industrial system. Success in implementation of circular economy would permit the decoupling of growth from the consumption of resources leading to resilient growth, less reliant on resources (European Commission, 2014).

2.2 Previous Circular economy reviews

Some review studies are mentioned here to clarify the need for this study. One of the first reviews on circular economy was conducted by Ghisellini et al. (2016). The authors summarize and compare circular economy implementation and practices of China with Europe, Japan and the world in order to understand similarities and differences between them. The review covers (from 2004 to 2014), and details the origins of CE and its implementation across three stages; micro, meso and macro level. The review found that a successful transition towards CE needs the involvement of all actors of the society as well as appropriate collaboration and exchange between them, while companies and investors also need an economic return as motivation.

Similarly, Lieder and Rashid, (2016) perform a comprehensive review of literature on CE based on 136 articles from 1950-2015, covering aspects of resources scarcity, waste generation and economic advantages. They also underline the importance of stakeholder involvement and support for the successful implementation of CE. Discussion on CE is highly granular and little on the implementation phase according to Lieder and Rashid, (2016). Most work has been on resources scarcity and environmental impact. Ghisellini et al. (2016) review only a ten-year period. In order to have an overall view of the future directions in CE studies, this review covers 2000 to 2016 in order to reconstruct a new literature review study based on most recent publications in the area.

2.3 Systematic Literature Review

In this research, a systematic and comprehensive literature review is carried out. The systematic review is carried out in order to give a picture of the current state of circular economy research. The comprehensive review is carried out to supplement the systematic review and to make sure that any important or relevant literature not covered by the systematic review is captured. The present study employs a systematic literature review, analysing articles covering circular economy published from 2000 to 2016. A total of 510 articles were retrieved from Scopus. Scopus was chosen because it is the largest database of peer-reviewed literature, scientific journals, books and conference proceedings.

The review was mainly conducted as a structured key-word, title and abstract search, and the term "circular economy" was used. It is worth noting that the choice of this keyword was based on the keyword used by Ghisellini et al. (2016) and Lieder & Rashid (2016). Content analysis method was adopted for the comprehensive literature review. A secondary source of literature was the cited references from the chosen papers. The study was conducted covering literature (available online) based in the English Language. During the literature search, no time range was set so as to cover all the relevant/ important literature. Grey literature on the concept of CE which has been growing is also discussed.

2.3.1 Distribution across the time period and main journals

The systematic review attempts to analyse 510 articles published between 2001 and 2016 as illustrated in Fig. 2.1 indicating that the concept of CE is a research field that has grown rapidly over the last decade. From the current trend, there is likely to be increased growth in publications on the concept. As can be seen, the number of publications has nearly tripled between 2013 and 2016 (111 publications in 2016 by June in comparison to 30 publications in 2013). This upward trend has coincided with the adoption of China's CE law.

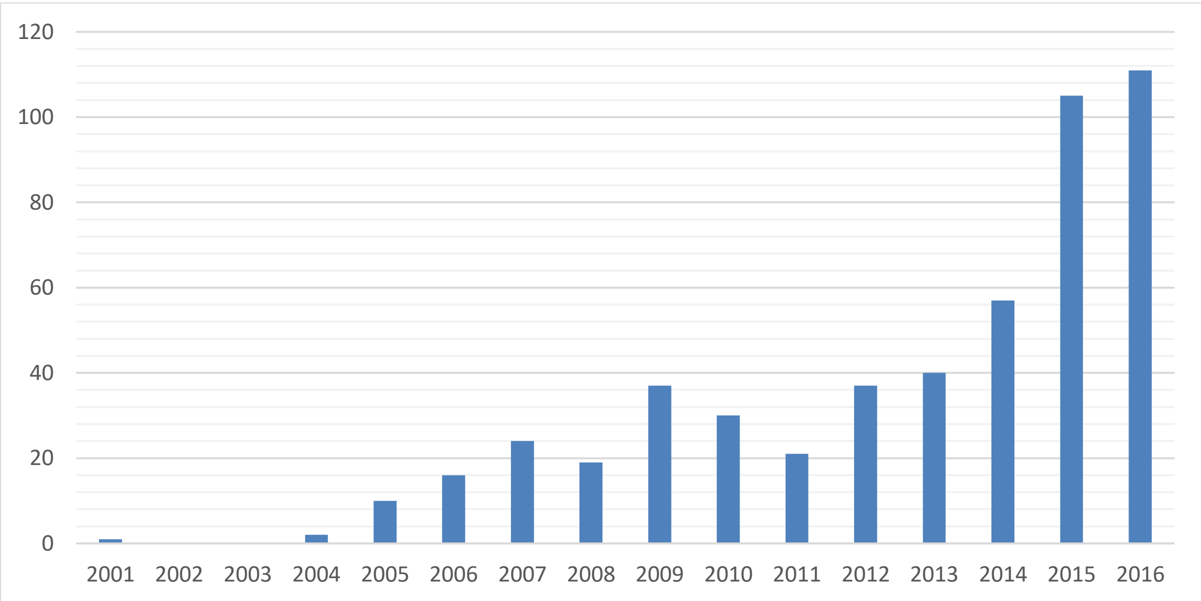

Figure 2.1: Time distribution of sample publications. (Source: Scopus™; keywords: "Circular economy").

Table 2.1: Ranking of journals by subject area

Subject area	Papers
Environmental Science	271
Engineering	163
Energy	114
Social Sciences	92
Business, Management and Accounting	83
Chemical Engineering	55

Agricultural and Biological Sciences	48
Economics, Econometrics and Finance	45
Materials Science	37
Chemistry	28
Computer Science	25
Earth and Planetary Sciences	25
Mathematics	22
Medicine	15
Decision Sciences	9
Physics and Astronomy	9
Arts and Humanities	7
Multidisciplinary	6
Biochemistry, Genetics and Molecular Biology	4
Pharmacology, Toxicology and Pharmaceutics	3

(source: Scopus^{TM}; keywords: "Circular economy").

Scopus categorizes titles using the ASJC (All Science Journal Classification) scheme and the classification is based on the aims and scope of the title, and on the content it publishes (Scopus, 2017). Scopus classifies titles into four categories; Physical Sciences, Health Sciences, Social Sciences and Life Sciences, each with its own further sub-classifications. Circular economy research has mainly been confined to the Environmental Sciences domain, as shown in the following Table 2.1. Environmental sciences fall under the physical science classification and accounts for more than half of the publications between 2000-2016. The second most researched domain is engineering followed by energy. The Business, management and accounting domain is slowly receiving more attention. There are some articles coming from business and management journals (and you can make some examples, citing some of these papers). It is evident that research into the economics of CE is at its infancy with only 45 publications on the subject matter. It is fairly surprising to see that no contribution about the CE has been published in mainstream Economics/Management journals. This seems to suggest that a critical evaluation of the Circular economy paradigm and of its economical and managerial implications has not been fully conducted yet.

Table 2.2: Distribution of the papers according to document type. (Source: Scopus)

Document type	**Papers**
Article	459
Review	51

The distribution by document type is shown in Table 2.2. The list is made up of two types of documents namely; articles and reviews. Articles refer to original research or opinion consisting of journal articles that have been peer-reviewed as well as case reports, technical and research notes and short communications. Articles also include articles in press which contribute 44 of the total 459. Articles-in-press refer to articles that have been accepted and made available online before official publication. The majority of publications were articles. Lastly, reviews are significant review of original research, and also include conference papers.

Table 2.3: Distribution of the papers according to geographical consideration (Source: Scopus)

Country/Territory	**Papers**
China	273
United Kingdom	42
Netherlands	29
Germany	25
United States	23
Italy	22
Belgium	17
Sweden	16
Japan	15
Australia	10
Spain	10
France	9
Finland	8
Austria	7
Canada	7
Denmark	5
Greece	5
South Korea	5
Undefined	43

The distribution of publications by geographical location is shown in Table 2.3. The list covers a range of countries, with some publications having no country affiliation. Research with focus on CE and related issues within China makes up the majority of all CE research literature with 53%. The table also shows that the subject of circular economy is gaining considerable interest from European countries like the United Kingdom, Netherlands and Germany. This growth can be attributed to The European Commission’s new circular economy Package presented in December 2015. The package is made up of an action plan setting out a series of measures to improve waste management, promote eco-innovation and resource efficiency planned for the coming years as well legislative amendments on waste and landfill, reuse and recycling targets (European Parliament, 2016).

Table 2.4 shows the most active authors in the circular economy research. Yong Geng of Shanghai Jiao Tong University is the most active with 11 publications so far. The list of top authors comprises mainly of Chinese authors. This is not a surprise given the rise of circular economy in China (Yuan, 2006; Geng, 2012) and supports the findings of Table 2.3.

Table 2.4: Distribution of the papers according to authors (Source: Scopus)

Author Name	**Papers**
Geng, Y.	11
Bi, J.	6
Hu, Z.	5
Zhao, Y.	5
Zhu, B.	5
Zhu, Q.	5
Yuan, Z.	5
Zhang, T.	5
Chen, D.	4
Fujita, T.	4
Hara, K.	4
Kopnina, H.	4
Shi, L.	4
Uwasu, M.	4
Wen, Z.	4
Xue, B.	4
Yabar, H.	4
Zabaniotou, A.	4
Zhang, H.	4
Chertow, M.	4
Hu, S.	4

Note: the table only shows authors with four or more publications. A complete table containing the list of all authors is provided in appendix 1.

Table 2.5: Ranking of journals by number of publications. Source: Scopus

SOURCE TITLE	**Papers**
Journal Of Cleaner Production	58
Xiandai Huagong Modern Chemical Industry	22
Resources Conservation And Recycling	21
Shengtai Xuebao Acta Ecologica Sinica	15

Journal Of Industrial Ecology	14
Sustainability Switzerland	12
Zhongguo Renkou Ziyuan Yu Huan Jing China Population Resources And Environment	12
Waste Management	11
Bioresource Technology	10
Zhongguo Huanjing Kexue China Environmental Science	8
Energy Education Science And Technology Part A Energy Science And Research	6
Journal Of Material Cycles And Waste Management	6
Nongye Gongcheng Xuebao Transactions Of The Chinese Society Of Agricultural Engineering	6
Qinghua Daxue Xuebao Journal Of Tsinghua University	6
Wuhan Ligong Daxue Xuebao Journal Of Wuhan University Of Technology	6
Xitong Gongcheng Lilun Yu Shijian System Engineering Theory And Practice	6
Chinese Journal Of Ecology	5
Environmental Science And Technology	5
Kang T Ieh Iron And Steel Peking	5
World Journal Of Modelling And Simulation	5
Journal Of Ecology And Rural Environment	4
Meitan Xuebao Journal Of The China Coal Society	4
Renewable And Sustainable Energy Reviews	4
Waste Management And Research	4
Chung Kuo Tsao Chih China Pulp And Paper	3
Environment International	3
Environmental Innovation And Societal Transitions	3
Environmental Science And Pollution Research	3
Futuribles Analyse Et Prospective	3
International Journal Of Life Cycle Assessment	3
International Journal Of Sustainable Development And World Ecology	3
Journal Of Convergence Information Technology	3
Physicochemical Problems Of Mineral Processing	3
Research Journal Of Applied Sciences Engineering And Technology	3
Science Of The Total Environment	3
Sustainability Science	3
Waste And Biomass Valorization	3
Others (2 and below)	163

The distribution by journal is shown in Table 2.5. The Table shows that the subject of circular economy is considered by a large number of journals. The Journal of Cleaner Production is clearly the leading journal in this context as evidenced in our results. The large number of publication in the Journal of Cleaner Production that focuses on environmental, and sustainability research and practice further explains the high number of publications in the environmental sciences domain. A wide range of journals that have published articles on the CE was found, indicating a distribution across a wider range of journals. A number of

Chinese journals cover the concept CE. For example, the Xiandai Huagong Modern Chemical Industry which covers the Subject Area of Chemical Engineering ranks second with 22 publications. The growing Chinese uptake of the concept is attributed to the adoption of the Circular economy promotion law in China in 2009 (Yuan, 2006; Geng, 2012).

2.4 Evolution of Circular economy

There have been numerous studies looking at the roots of CE (See Pearce and Turner 1989; Frosch 1992; Ehrenfeld and Gertler 1997; Erkman 1997; Van Berkel et al. 1997; Chiu and Geng 2004; Andersen 2007; Ren 2007; Zhu and Wu 2007; Mathews and Tan 2011; Ellen Mac Arthur Foundation 2013; Preston 2012; Iung and Levrat 2014).

Table 2.6: Circular economy (CE) origins

Circular economy (CE) origin	**Reference**	**Description**
Earth as a space ship Kenneth Boulding (1965)	Hu et al., 2011	The earth as a closed economic system in which the economy and the environment are characterized by a circular relationship
Economics of Natural Resources and the Environment Pearce And Turner (1990)	Su et al., 2013	They view earth as a closed economic system, with the economy and the environment linked through a circular relationship
Industrial Ecology	Graedel, 1996; Yuan et al. 2006;	Industrial activity should be viewed and analysed in the same way as a biological ecosystem
Biomimicry - Janine Benyus *Regenerative Design*- John T. Lyle *Performance Economy*- Walter Stahel	Ellen Mac Arthur Foundation, 2013; Stahel, 2006;	-Studying nature's models and imitating them to solve human problems. - All systems can be arranged in a regenerative manner. -Selling services rather than products, concerned with waste prevention, product life extension and life-long goods.

While no one is certain about the origin of the term '*circular economy*', a lot of authors commonly attribute it to American economist Kenneth Boulding (Hu et al., 2011). Boulding (1965) in his article titled *Earth as a Spaceship* suggested that the Earth was like a single spacecraft flying through space, continuously exhausting its limited resources in order to survive. If natural resource exploitation and environmental damage continued beyond repair, then the earth would ultimately be damaged, quite like a spaceship that has taken damage beyond its recovery capacity. Therefore, if the spaceship (earth) wanted to survive, the old consumption-focused form of economy needs to be replaced with a circular one, which is able to continuously reproduce its needs in an ecological cyclical manner.

Similarly, it is argued that the concept of circular economy can be traced to Pearce and Turner, two British environmental economists and their work of 1990 titled "Economics of Natural Resources and the Environment". They indicated that the environment is being treated as a waste reservoir as a result of the traditional open-ended economy, which was designed with no inclination for recycling. However, confronted with present environmental problems and resource scarcity, there is a need to view earth as a closed economic system, with the economy and the environment linked through a circular relationship rather than a linear one (Su et al, 2013). They analysed the relationship between economic and natural systems and proposed a closed-loop of material flows in the economy, which was termed circular economy.

The roots of circular economy can also be traced back to industrial ecology. Industrial ecology is a theory developed in the 1970s, which studies industrial processes and their material and energy flows. Industrial ecology suggests that industrial activity should be viewed and analysed in the same way as a biological ecosystem, ultimately striving towards the integration of activities and cyclization of resources like natural ecosystems (Graedel, 1996). The most common example of industrial ecology is industrial symbiosis. Industrial symbiosis involves the co-location of traditionally separate companies/industries and enables the exchange of wastes, by-products, and energy among them. The industrial district at Kalundborg, Denmark (Figure 2.2) is a good example of industrial symbiosis (Ehrenfeld & Gertler, 1997).

The Kalundborg model consists of a power plant, an oil refinery, biotechnology facility, a plaster-board manufacturing plant and the local Kalundborg municipality exchanging energy, materials and waste. This model has not been replicated in Europe so far, while in China Industrial Eco-Parks are a growing model. The Suzhou New District (SND) is an example of circular-economy initiatives. The SND is larger than Kalundborg in Denmark, has grown at a much faster rate due to top-down approaches and by 2014, the SND hosted more than 16,000 enterprises and almost 4,000 manufacturing firms (Mathews and Tan, 2015).

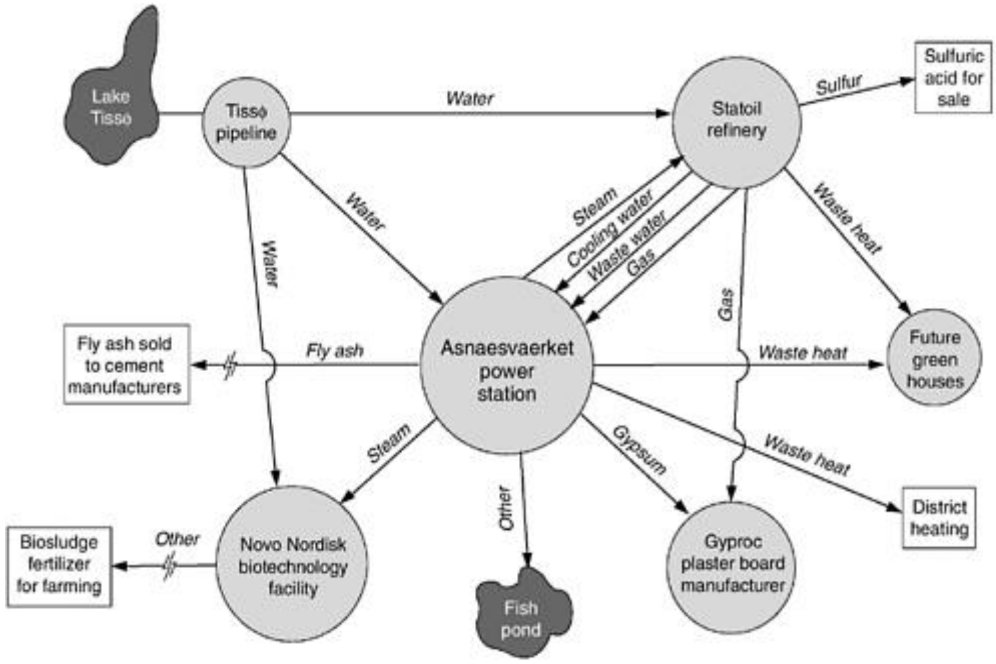

Figure 2.2: Industrial Ecosystem at Kalundborg, Denmark (Source: National Academy of Engineering. 1997)

The Closed Substance Cycle and Waste Management Act enacted by Germany in 1996 is one of the first legal steps towards a circular economy taken by a developed nation (Su et al., 2013). The law was aimed at reducing waste by integrating product responsibility into economic decision-making (Closed Substance Cycle Waste Management Act, 1996). Japan, Sweden, and the Netherlands are examples of other western countries promoting circular economy through legislation (Law for the Promotion of Effective Utilisation of Resources, 2000).

Recently, most of the attempts to develop circular economy legislation and applications are centred in China, since this country adopted the paradigm as its national development plan (Mathews and Tan, 2015; Lieder & Rashid, 2016). China sees CE as a new development model that will help it achieve a more sustainable economic structure (Zhu, 2008; Geng and Doberstein, 2008).

A comprehensive review and critique of CE in China, distinguishing it from the western version is provided by Naustdalslid (2014). Naustdalslid (2014) states that CE in more developed industrialized countries is a bottom-up microeconomic approach promoted by environmental organisations, civil society and NGOs through pressure on the establishment to put up legislation and regulation. CE in china on the other hand is a top-down national government political and socioeconomic policy aimed at overall societal transformation. The author argues that social and income discrepancies, low resource utilization efficiency in addition to environmental degradation and pollution lead to China's CE. China views CE as an environmental-economic development system which would lead to a more harmonious society for man and nature. Inadequate indicators, inadequate supporting policy, little bottom-up involvement are among the challenges confronting the implementation of CE.

The CE came to prominence in china in the 1990s with origins in cleaner production, industrial ecology and ecological modernization thought, taking inspiration from Europe and japan where it had been successfully implemented. The Circular economy Promotion Law; China's main national-level framework for pursuing the CE was adopted in 2009. A number of publications provide more details of China's CE framework (e.g. Geng and Doberstein 2008; Su et al. 2013; and Mathews and Tan 2016).

The Chinese perspective on the CE was developed around issues of pollution and in the context of China's rapid growth. China was experiencing rapid industrial and economic growth that brought with them severe environmental damage and the need for a new model to reconcile sustained growth with environmental concerns. The challenge for China was that of aligning growth with social and environmental fears. CE from the Chinese perspective is the broader in terms of breadth than the European one also covering: materials, resources, and waste, and including a prominent role for pollution concerns, as well as resource efficiency (McDowall et al. 2017). whereas The European approach places more emphasis on consumption, China overlooks measures to influence patterns of consumption. Rather, putting more attention on measures to increase efficiency and reduce waste and pollution in manufacturing.

The issues of scale and geography are given paramount importance in China's model, which are almost entirely missing from the European approach. For example, a distinguishing feature of China's CE policies is the designation and funding of specific provinces, cities, or zones (such as industrial parks). China's CE policy also includes the integration of CE principles into land-use planning due to its current rural-urban transition (McDowall et al. 2017).

Recently, the circular economy package was adopted by the Commission in 2015, after several delays and pressure from stakeholders. The intention is to create support for the transition towards a more circular economy in the EU. This package consists of legislative proposals on waste, with long term targets to increase recycling and reuse while reducing landfilling. An Action Plan to support the circular economy in each step of the value chain is also included, in order to close the loop of product lifecycles, – from production to consumption, repair and manufacturing, waste management and secondary raw materials that are fed back into the economy.

The European CE focus is on business opportunities together with resource efficiency goals. CE became prominent only very recently due to fears around high commodity prices, despite its origins from Europe. The attention is mainly on materials, resources, and waste and much less on broader environmental pollution (McDowall et al. 2017). The European approach places more emphasis on consumption and product design compared to the Chinese approach. Europe's already existing well-developed eco-design system, covering a wide series of household goods makes it easier to extend the system to cover CE.

The European approach towards CE varies considerably among EU member states with a handful of countries namely Austria, Germany, and Finland having specific policies for CE and resource efficiency and with only Austria having set targets and a timeline (McDowall et al. 2017). CE in Europe is driven by the need to foster growth, despite environmental constraints, capture the value of wastes as secondary raw materials through resource efficiency, and innovation.

Europe's emphasis on design, incentives for repair, and product labelling regulations could help China to embrace the principle of reuse and move beyond recycling as the economy continues to grow. On the other hand, the extensiveness of the experimentation in policy and planning in China (directed toward recognising and upscaling success) may be a beneficial example for Europe (Bocken et al., 2017).

Table 2.7 displays legislative policies adopted in some countries promoting circular economy.

Table 2.7: Legislation promoting Circular economy in certain Countries

Country	**Policy title**	**Date**	**Objective**
Germany	The Closed Substance Cycle and Waste Management Act	1996	Reducing waste by integrating product responsibility into economic decision-making
Japan	Law for the Promotion of Efficient Utilization of Resources, passed in 2000.	2000	Manufacturers are legally required to also run disassembly plants, with material recovery a legally mandated as well.
	Fundamental Law for Establishing a Sound Material-cycle Society	2000	Resource conservation
China	Circular economy Promotion Law of the People's Republic of China	2008	Facilitating circular economy, raising resources utilization rate, protecting and improving environment and realizing sustained development.
	State Council	2013	Provide further details for specific sectors and provide clarity on the implementation of the provisions of the CE promotion law
Denmark	Resources Strategy, ‘Denmark without Waste’.	2013	Recycle more, less incineration
	Green Transition Fund	2014-2016	To create industrial symbiosis
Netherlands	A Circular economy in the Netherlands by 2050	2016	50% reduction in the use of primary raw materials (minerals, fossil and metals) by 2030, giving the highest priority to: biomass and food, plastics, manufacturing, construction,

			and consumer goods
	From Waste to Resources" programme (VANG)	2014	Stimulate the transition towards a circular, waste-free economy
EU	Circular economy Package	2015	Closing the loop" of product lifecycles through greater recycling and re-use, and bring benefits for both the environment and the economy.

Most recently, the Ellen MacArthur foundation, a non-governmental organisation founded with the purpose of promoting the CE, together with its industry partners has been at the centre of the CE debate publishing several reports on the topic, gaining both political and business traction. The Ellen MacArthur foundation (EMA) attributes CE to more current concepts and policies such as biomimicry, regenerative design, performance economy, cradle to cradle, and blue economy (Ellen Mac Arthur Foundation, 2013). The EMA focuses on the implementation of these concepts in a free-market economy. That is the true challenge.

The move from a linear system of production and consumption (produce-use-dispose) that exposes the society to resource constraints, growing volumes of waste and pollution to a circular and more regenerative configuration could play a vital role in the move towards a more sustainable economic system where resources are used in a more efficient manner, cutting back on total waste generation and enabling the recovery of unavoidable wastes as raw materials for remanufacturing and production of new products.

However, this move along with emerging innovations and systems cuts across not just technical but also socio-economic spheres and would require changes in all parts of daily life. critical areas such as energy consumption, food supply and mobility are areas where change is most needed. It therefore requires a major undertaking to encourage new production and consumption models so they may compete and challenge dominant societal practices.

Consequently, the new production and consumption models would have to look beyond recycling alone and also consider reduce and reuse dimensions. Reduction can be achieved from the production perspective in terms of using less resources and efficient product design. reduction can also be achieved in terms of consumption (consuming less).

Traditionally reduction has been associated with economic downturn but more recently there have been growing calls for the two concepts to be decoupled as well as calls for new economic indicators other than GDP (Wanget al., 2013).

A powerful new consumption model, which could lead to a significant reduction in production, consumption and waste generation is the so-called sharing economy (SE) or collaborative consumption. In this new model of consumption, consumers are increasingly interested in leasing and sharing products rather than owning them. As put by Matzler et al. (2015), the sharing economy 'seems to hold the potential to unite cost reduction, benefit augmentation, convenience and environmental consciousness in unified mode of consumption. Companies therefore should understand and manage this emergent system in order to adapt current and future business models to provide new sources of revenues within this growing area of the economy'. Adapting to this new consumption model will turn a challenge into an opportunity. In this recent study, Matzler et al. (2015) suggest six ways in which companies can respond to the rise of collaborative consumption by: (1) selling a product's use rather than ownership, (2) supporting customers in their desire to resell goods, (3) exploiting unused resources and capacities, (4) providing repair and maintenance services, (5) using collaborative consumption to target new customers and (6) developing entirely new business models enabled by collaborative consumption. All these principles constitute good steps towards a CE. Prominent examples are AirBnB and car-sharing clubs that have received the most attention. The benefits of SE include efficiency gains, greenhouse gas emissions mitigation and greater social capital promotion. Getting consumers "on board" with reengineered business models will arguably be a substantial challenge. In short, the CE needs to be considered as a social, cultural and political project, as well as a business, scientific, and technological endeavour (Hobson and Lynch 2016). It must be said, however, that, despite these needs, the CE concept has undergone a depoliticisation process in the public debate, by means of which it has become more of a *greenwashing* tool applied to corporate contexts (Valenzuela and Böhm 2017). Efforts to link it to the sharing economy or other concepts such as degrowth, the diverse economy and to perspectives that challenge the quantitative growth mechanisms must be made.

2.5 Circular economy barriers and drivers

2.5.1 Circular economy barriers

The concept of circular economy and barriers to it has received increased attention from industry, governments and academia over the last few years (Lieder & Rashid, 2016).

(See van Hemel and Cramer, 2002; Presley et al., 2007; del Brio et al., 2008; D'Amato and Roome, 2009; Sarkis et al., 2010; Mathews & Tan 2011; Kok et al. 2013; Park and Chertow 2014). Moving to a circular economy would require changes in all the parts of the value chain and affects all stakeholders. Abu-Ghunmi et al (2016) study the opportunity cost of not adopting circular economy in the water industry terming it as "closing the loop charge". Barriers to CE include prices that do not reflect externalities and therefore encourage linearity. Kok et al. (2013) produced a report commissioned by Circle Economy and presented one of the first analysis of barriers for a circular economy. They discuss the need for a CE, as well as necessary steps required to adopt a CE. The barriers were grouped into five categories namely: financial, institutional, infrastructural, societal and technological.

Institutional barriers comprise of obstacles as a result of existing laws. In the US, Germany and Japan for example, where there exists stringent waste and recycling laws, these laws hinder the exchange of waste between companies which is the bedrock of CE (Mathews & Tan, 2011). Flexible regulatory control in places like China on the other hand creates numerous opportunities for closing the loop driven by the market (Su et al, 2013). Funding sources are critical to CE. The need for large up-front capital investment to set up CE practices such as cleaner technology, eco-industrial parks is enormous and poses financial barriers. Inadequate financial support from banks and poor public tax incentives prevent enterprises from fully embracing CE principles (Mathews & Tan, 2011).

Technology is an important factor in the adoption of a CE. CE adoption at all levels requires advanced technology and development and the upgrading of systems and equipment. Sometimes countries especially developing may not possess the technical know-how and have to rely on other far more advanced countries which could lead to the "locked-in effect" (Mathews & Tan 2011). In other instances, companies do not have sufficient economic incentive to embark on cost and time-consuming technological changes that would bring about improved efficiency, waste reduction and reclamation. Another stumbling block in the move towards circular economy is the deep rooted nature of linear technologies (Park and Chertow, 2014).

2.5.2 Circular economy drivers

Stakeholders engage in circular economy for different reasons. From literature circular economy drivers include resource scarcity, environmental degradation good business opportunities, compliance with regulation, consumer pressure, collaboration with customers, and improved firm performance (Govindan et al.; 2015; Zhu & Geng 2013; Geng and Dobersteinm 2008; Yin and Ma, 2009; Geng et al., 2012). Andersen (2007) introduced environmental economics and highlighted its potential for use in applying circular economy. According to the author, the concept of circular economy has its roots in industrial ecology. It also touches the four economic functions of the environment; (1) amenity values; (2) a resource base for the economy; (3) a sink for residual flows; (4) a life-support system (Andersen, 2007). Capturing the effects on the environment through the pricing of externalities has significantly helped economic analysis.

Abu-Ghunmi et al (2016) state that CE can be promoted by incentives such as opportunity cost (shadow prices) payments to circular economy promoters in the form of subsides or directs payment. Stakeholder interaction is called for when deciding and advocating for a full cost recovery approach to pricing resources. Drivers such as legislation, information collection, and education are needed to promote to acceptance and move to circular economy. Awareness also affects realization of circular economy according to Ilic & Nikolic (2016). They explored Circular economy possibilities in Serbia with focus on waste management and identify four drivers namely: basic drivers consisting of waste collection and waste, public health, resource management (environment) and economic-financial capacity. It is therefore important to further understand the drivers of CE so as to carefully assess already existing policy options and new ones that would be required going forward. It is also paramount to include all stakeholders in the process so that motives can be aligned and converged to avoid prioritisation of one benefit over another (social, environmental and economic).

2.6 Circular economy implementation

Various studies have discussed the concept of CE implementation. (See Zhijun and Nailing, 2007; Geng and Doberstein, 2008; Li et al., 2010; Zhu et al., 2011; Su et al., 2013; Ma et al., 2014; Wu et al.,2014). The implementation of circular economy is also an increasingly explored field. Table 2.8 shows examples of a transition to Circular economy in case study companies collected by the Ellen MacArthur Foundation, (2015).

Table 2.8: Transition to Circular economy in Companies

Company	Sector	Action/Strategy	Result
Google	Information	Google data servers	In 2015, around 75% of

	Technology	maintenance and repairs	components used were refurbished
		Servers build program: using the refurbished components to build remanufactured servers	In 2015, 19% of servers were remanufactured
		Reuse and redistribute: redistribution of any excess component inventory internally before selling on the secondary market	In 2015, Google resold nearly 2 million units into the secondary market for reuse by other organizations
Sintronics	Electronic and Electrical equipment Electronics	Knowledge, capacity building, stakeholder engagement	97% of recovered material is now returned directly into the supply chain,
Cirkle	Food and groceries	Taking back waste streams from their customers	Cirkle re-use or recycle more waste than they actually create, and monetise collected refuse for the benefit of local charities. Reducing consumer confusion in recycling
DLL	Machinery and automotive-Asset-based financial solutions	Refurbishing old ambulance boxes and mounting them on new chassis	Investment costs for the end customer can be reduced by more than 20% and life of the vehicle is extended
Toronto Tool Library and Sharing Depot	Electronic and Electrical equipment (DIY Sector)	Shared use business model	Supports product life extension Reduces cumulative transactional cost

(Source: Ellen MacArthur Foundation, 2017 https://www.ellenmacarthurfoundation.org/case-studies)

Yuan et al (2006) present a three-layer approach to implementing circular economy heavily linked to theories of cleaner production, industrial ecology and ecological modernization. The first layer is the individual firm or micro level concerned with cleaner production and environmentally friendly product design. The second layer or meso level deals with eco-industrial networks and parks (Ghisellini et al, 2015). Activities such as sharing infrastructure, exchanging by-products and recycling waste are practiced at the meso level. Lastly, the macro level which involves scaling up from an eco-industrial park to an eco-city or eco-province concerned with not just sustainable production but also consumption.

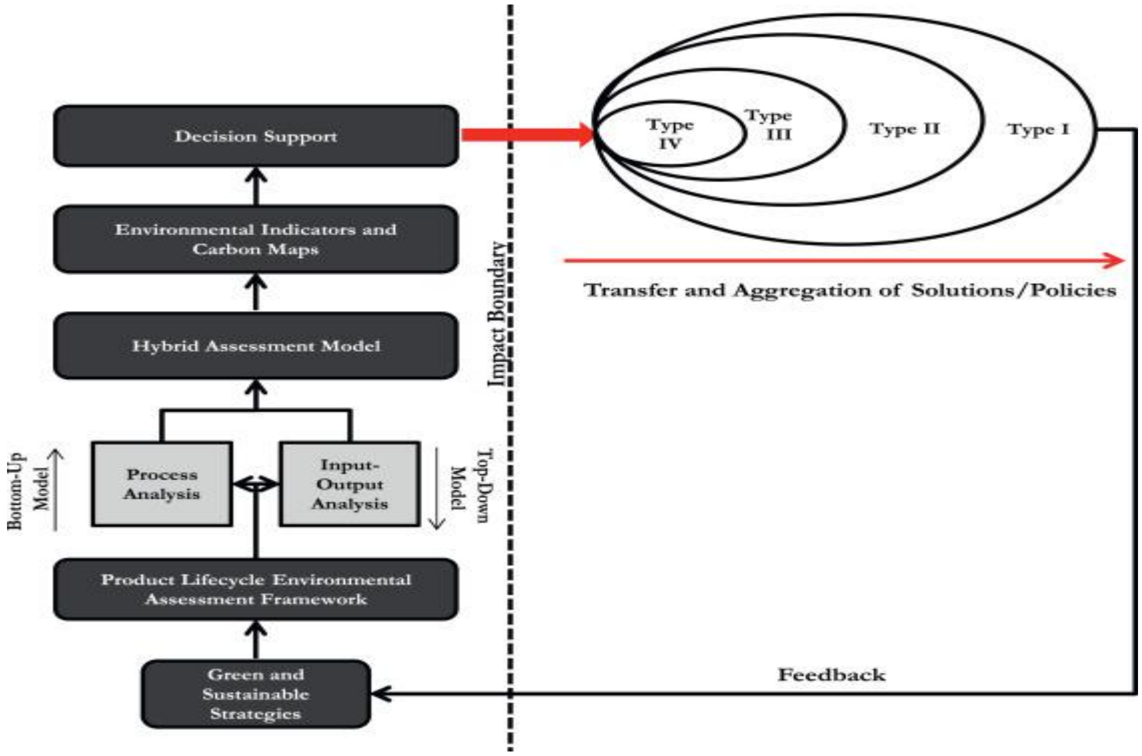

Figure 2.3: Bottom-up sustainable pathway framework (source: Genovese et al., 2017)

Park et al. (2010) explored firms and organizational ability to find a balance between economic growth and environmental conservation as well as the challenges and opportunities of doing so using ecological modernization theory within the context of ‘circular economy’ policy paradigm. Instead of looking at a single firm, their work made use of three case studies from the information technology industry and revealed how both firm-level and industrial-level value can be achieved in terms of cost reduction, revenue generation, resiliency, and legitimacy. Their work was qualitative in nature and lacked quantitative evaluation. The authors stress that Ecological modernization theory is a relevant management theory that suggests that technology and Innovation can help organizations improve on both environmental and economic dimensions. Ecological modernization theory was chosen ahead of the resource based view (RBV) because it provided a complementary and more robust understanding into how environmentally sound practices and improved technologies led to improved business value.

A descriptive examination of energy conservation and resource utilization in energy intensive process industries in China since its adoption of circular economy is offered by Li et al. (2010). The focus is on resource utilization. Firstly, they provided insight into the progress made in the process industries in terms resource utilization citing the ammonia industry, utilization of low-grade heat, coal fly ash and desulfurized waste. They then looked at energy conservation using case studies and also found notable progress made through the adoption of cleaner production in energy-intensive enterprises, establishment of eco-industrial parks, and waste recovery and recycling in industrial processes.

Circular economy is viewed as an environmental management concept by Zhu et al (2011) that can be implemented at three levels, the regional, industrial zone and individual enterprise level. Using hierarchical regression analysis and surveying 396 Chinese manufacturers, Zhu et al (2011) explored environmental supply chain cooperation and its linkages to circular economy implementation and performance outcome achievements. The result indicated the usefulness of environmental supply chain cooperation in addition to highlighting the need for manufacturers to improve supply chain coordination in their implementation of CE.

Su et al. (2013) studied circular economy in China and compared Dalian city with other pilot cities (Beijing, Shanghai and Tianjin). They revealed that CE practices are being carried out at the micro, meso and macro levels at the same time, covering the areas of production, consumption, and waste management. The authors suggest that successful implementation of CE in China is hampered by issues such as lack of reliable information, shortage of advanced technology, poor enforceability of legislation, weak economic incentives, poor leadership and management, and lack of public awareness. Overcoming these challenges would enhance CE implementation. Su et al (2013) focused on the macro level of CE implementation looking at whole CE cities rather than individual firms.

2.6.1 Circular economy at the micro level (study with case studies)

Studies focusing on CE at the micro level with particular interest in cleaner production (See Van Berkel et al. 1997, Fresner 1998; Van Berkel 1999, 2000, 2007; Gwehenberger et al. 2003; Frondel et al. 2004; Cagno et al. 2005; Yap 2005; Yuan et al. 2006; Brown and Stone 2007; Ren 2007; Schnitzer and Ulgiati 2007; Fang et al. 2007; Feng and Yan 2007; Geng and Doberstein 2008; Bonilla et al. 2010; Geng et al. 2010b; Li et al. 2010; Ramani et al. 2010; Wrinkler 2011; Geng et al. 2013; Su et al. 2013; Zhang et al. 2013; Liu and Bai 2014; Prendeville 2014). Several others using case studies in industries such as paper and iron and steel with respect to circular economy have been carried out (Du and Cheng 2009, Dong et al 2013, Ma et al, 2014; Li and Ma, 2015; Park et al. 2010). Using dynamic material flow analysis, a forecast of production, recycling and consumption of iron ore in the Chinese steel cycle is undertaken by Pauliuk, Wang and Müller, (2011) up to the year 2100. The full cycle is studied to figure out likely reaction of the steel industry in relation to the circular economy concept. They forecasted a shift from linear to cycle process chain as well as substantial growth in scrap metal. A scenario analysis identified three major challenges namely; a peak and drop in consumption, a sharp rise in scrap flows and quality requirements of steel. The results of the study indicated that an abundantly large stock of mature in-use stock of steel, a shift toward recycling by the whole industry and lastly waste management techniques that allow recycling of steel scrap into its original product category, were conditions needed to establish a circular economy of steel.

A number of studies focused on national large and medium scale enterprises. Few have purposely examined private enterprises. Ma et al (2014) considered at a private steel conglomerate based in China. They formulated a circular economy performance measurement system they term circular economy efficiency composite index, based on four indicators namely level of equipment used, utilisation level of materials, emission level of pollutants and fresh water consumption level. Based on the generated index, the results indicate the private steel city has improved significantly with scope for further improvement. Government laws and policies have also played a part. The primary means of creating circular economy in the iron and steel industry has been the closure of outdated production plants and the rapid move to cleaner production techniques. The authors suggest building a partnership between the national and private iron and steel enterprises.

While a lot of studies have examined circular economy and resource and ecological efficiency from the perspective of countries, cities and industrial parks, Ma et al, (2015) examine in the application of circular economy at the firm level using a phosphorous chemical firm as a case study. They stress the importance of firms as the primary implementers of circular economy. The study proposes the combined use of analysis tools as well as assessment tools, eco design and decision tools to design and construct circular economy within a firm. Results from Ma et al, (2015) reveal improvements in economic benefit, utilization efficiency and eco-efficiency. A large number of these studies are based on China, where there exists strong legislation as well as central planning from the government to promote, and implement circular economy principles. There is a need to explore circular economy from other parts of the world for a more comprehensive view (Ghisellini et al, 2015).

2.6.2 Circular economy at the meso level

A large number of publications related to Circular economy have been focused on the introduction of eco-industrial parks (Chertow, 2000; Korhonen, 2001; Fang et al., 2007; Yang and Feng, 2008; Yuan et al., 2010). Geng and Cote, 2003; Geng et al., 2010; Shi et al., 2010: Zhang et al., 2010: Matthews and Tan, 2011; Bai et al. 2014). These parks benefit from industrial symbiosis and require large investments, usually from government. A review of a number of eco-industrial initiatives taken in China was undertaken by Mathews and Tan (2011). The review looked at eco-industrial parks in China and compared them with international parks in Denmark, Australia, Korea and Japan. It is observed that most of the eco-industrial parks (both Chinese and International) were not purposely designed/built parks but have rather evolved and transformed over time, with activities such as environmental protection, supply chain integration, and regional synergy capture occur occurring naturally.

Another finding was the low symbiotic intensities in the Chinese parks, attributed to the parks infancies compared to the older international parks. The parks in China also have very dominant government involvement in their creation and management.in contrast; the international cases have a more autonomous structure and management. They suggest that despite possible disadvantages like strong competition while accessing established markets and technologies, China might be benefiting from latecomer advantages from adopting a circular economy framework and consequent systematic promotion of eco-industrial projects. Mathews and Tan (2011) reach the conclusion that substantial competitive advantages could be gained from careful application of circular economy legislation. A top-down approach and a bottom-up approach are needed, complementing each other to drive circular economy initiatives. Furthermore, Li and Ma (2015) focus on how to create a circular economy park, using the papermaking industry as a case study. They show that detailed planning is required to set up a circular economy park. The results show that highly energy intensive industries can form a synergy.

2.6.3 Circular economy at the macro level

Considerable work has been conducted on circular economy indicators and performance (Feng and Yan 2007; Geng et al., 2009; Geng et al., 2012; Geng et al. 2012**;** Preston 2012; Ren et al. 2013; Su et al., 2013; Zaman and Lehman 2013; Park and Chertow 2014; Wu et al., 2014; Golinska et al. 2015;). In their study, Geng et al. (2012) provide a descriptive overview of the national circular economy indicator system in China. This indicator system directs implementation of CE initiatives in addition to evaluation. Geng et al. (2012) stressed the importance of indicators as useful metrics for policy and decision making. They found that benefits could be gained from implementing the indicator system. However, the authors felt that a comprehensive systematic review would be necessary as the indicator system needs to cover social, business, prevention-oriented, absolute-reduction, and industrial symbiosis indicators to complement traditional economic and environmental indicators. They also determined obstacles to its implementation namely: lack of detailed description or standardized process on data collection, the voluntary nature of the system, and no specific goals or benchmark. Circular economy indicators were also investigated by Geng et al. (2013). They argued that the existing indicators would not optimally assess circular economy and hence were incomplete. This was as a result of the indicators being originally not designed for a circular, closed-loop system. Some other shortcomings of the indicators mentioned by the authors include: being focused on single aspects of resource use and system function, accounting for nature and environment in only monetary terms, and lacking the capacity to deal with waste management and recycling and reuse policies.

As an alternative, an Emergy Indicator System embedded in ecology, thermodynamics, and general systems theory was introduced. According to Geng et al. (2013), the emergy indicator system can be integrated and used with our indicators such as LCA and MFA. By jointly applying substance flow analysis and resource productivity indicator, Wen and Meng (2014) quantitatively evaluated the performance of circular economy in the printed circuit board industry. The capacity for the substance to exit the system at numerous stages in the production chain in addition to complicated relationships between enterprises have rendered substance flow analysis at the industry chain level very challenging. The results showed that it is possible to enhance the resource productivity by prolonging the production chain. Waste utilization does have an impact on the resource productivity. Extending dominant industrial chains, introducing chains-matching projects and recycling companies, designing eco-industrial chains, and setting up an industrial symbiosis system all improve the resource productivity.

Similarly, Wu et al. (2014) deal with the efficiency of CE from a regional perspective. They carried out a dynamic evaluation on CE efficiency of 30 regions in China, over a 5-year period (2005–2010) through incorporating super-efficiency data envelopment analysis (DEA) model with DEA window analysis. The CE system is divided into three sub-systems, namely resource saving and pollutant reducing (RSPR) sub-system, waste reusing and resource recycling (WRRR) sub-system and pollution controlling and waste disposing (PCWD) sub-system. The evaluation reveals different performance levels for the sub-systems as well as different efficiency levels for the different regions of China. (PCWD) and (WRRR) efficiency was relatively high, while (RSPR) was low. They suggested that future priority should be given to (RSPR) and also raised the need to evaluate the suitability of uniform CE policies given the different regional performances. It is evident that there is no one accepted indicator for measuring CE. The studies reviewed all offered different yardsticks with which to measure circular economy, hence making circular economy adoption and monitoring difficult and confusing.

2.7 Awareness of Circular economy

Studies have looked at circular economy from an awareness and behavioural point of view (Gu et al., 2007; Yu, 2008; Wang, 2008; Lin et al., 2009; Liu, 2009; Xue et al. 2010; Zhu et al. 2011; Zhang et al. 2013; and Liu and Bai, 2014). Liu et al. (2009) conducted a survey and analysis on public awareness and performance for promoting circular economy with a case study from Tianjin, China. They collected data through questionnaires across six urban districts and interviewed 600 respondents. The results showed that there was limited awareness and poor understanding about circular economy among residents. Nevertheless, respondents had a positive approach towards garbage sorting with most residents organising their garbage into groups that can be sold, reused and or exchanged for new ones. They found a positive correlation between people's awareness of circular economy and educational level. Resource conservation and age of respondents also had a positive correlation.

Additionally, Liu and Bai (2014) explored firms' awareness and behaviour to developing circular economy. They examined 157 manufacturing firms using questionnaires and interviews and found that the firms had a good understanding of circular economy concept. However, the understanding did not translate to implementation due certain barriers.

They classified these barriers into three: structural, cultural and contextual. Circular economy awareness alone may not be enough. Action is needed. Understanding the barriers and policy options in addition to awareness could further promote implementation.

2.8 Circular economy and supply chains

Looking at circular economy from the supply chain perspective involves considering reverse supply chains, open and closed-loop supply chains. A reverse supply chain (RSC) consists of the activities of the collection and recovery of product returns in SCM. A Closed loop supply chain (CLSC) is one that is designed, controlled, and operated to maximise value creation over the life-cycle of a product, with dynamic recovery of value from different types and volumes of returns over time (Guide & van Wassenhove, 2006). The integration of a forward supply chain and a reverse supply chain results in a closed-loop supply chain (CLSC). In other words, there are both forward and reverse channels in CLSC networks. Product recovery and remanufacturing in a CLSC is primarily carried out by the original product or service provider. In contrast, an open-loop supply chain is a reverse supply chain where used products are recovered or returned to a third party or outside company, not the original manufacturer (Gou et al, 2008).

Circular economy considers both open and closed-loop supply chains with the emphasis on resource recovery and not on the party carrying it out. A circular economy "closes 'resource loops' in all economic activities in a sense that there is no 'end' within a circular economy, but a 'reconnection to the top of the chain and to various activity nodes in between" (Hislop and Hill, 2011). Circular economy aims to promote economic production systems that are connected with end treatment systems through reusing and recycling systems, thereby culminating in a closed loop of materials and energy flows.

There have been a number of studies relating circular economy and specifically supply chain management (Genovese et al. 2015; Nasir et al. 2017; Witjes & Lozano, (2016). The importance of sustainable public procurement SPP in the transition to circular economy is highlighted by Witjes & Lozano, (2016). Given the size of public procurement, it can be used to change behaviour of suppliers, set trends for other organisations and promote sustainable products and services. They argue that supply chain collaboration can lead to efficient resource utilisation and waste reduction but is not without its difficulties. These difficulties include coordination costs, vulnerability costs, information, bargaining and free riding. The qualitative study employs grounded theory, specifically analytic induction and proposes a conceptual framework linking SPP and SBM. The work is not empirical and concludes that stakeholder engagement is needed to identify relationship challenges.

Genovese et al., (2015) provide two case studies from the chemical and food industries, comparing linear and circular production routes across a number of indicators such as carbon emissions, and waste recovery. The study suggests that there are clear environmental gains from the incorporation of circular economy principles within sustainable supply chain management, but it might not be so straightforward due to market and policy implications.

The integration of circular economy principles within sustainable supply chain management is again proposed by Nasir et al., (2107) using a case study of two functionally similar building materials to show the environmental benefits in carbon emissions terms that can be realised through the adoption of a supply chain based on circular economy ideas as opposed to a traditional linear supply chain. The circular supply chain provides clear advantages from an environmental point view despite external supply chain influences and scenarios. While most studies focused on only carbon emissions as an environmental indicator, more relevant environmental indicators need to be considered to further widen the empirical evidence in support of circular production systems.

2.9 Circular economy in Grey Literature

The concept of circular economy has received a considerable amount of attention and publicity from individuals and organisations outside academia, none more so than Dame Ellen MacArthur and her foundation. The Ellen MacArthur foundation has been at the forefront of current Circular economy debate working with leading industry partners such as Phillips, Cisco, Google, etc. Its initial three volume report titled "Towards the Circular economy" discusses the limits of the linear consumption model and the need for a transition to circular economy which it defined as "an industrial economy that is restorative by intention and design". This is a widely used definition. The report brings together the concepts of cradle-to-cradle, biomimicry, industrial ecology, regenerative design, performance economy, blue economy and natural capitalism and underlined a multi-billion Euro opportunity for the European Union in the area of consumer durables.

A report by the Waste and Resources Action Programme (WRAP) *Economic Growth Potential of More Circular Economies* highlights the benefits of circular economy by using more labour and less resources. It also estimates that 1.2 to 3 million jobs in Europe could be created by 2030 through the expansion of circular economy efforts. A similar report also found that the UK economy is already around 20 per cent circular with the potential to grow. In its 2014 report titled "Growing a circular economy: Ending the throwaway society," the UK's House of Commons Environmental Audit Committee says, the present economic consumption model is unsustainable. The committee also describes the current linear production and consumption system as wasteful to natural resources and damaging to the environment, stressing that growth from developing countries would only put further pressure on volatile commodity prices. A circular approach promoting the reuse of resources made both environmental and economic sense according to the committee. The committee also observed that there is the potential across the economy of billions of pounds of benefits for businesses as a result of resource efficiency brought about by adopting a circular economy.

The Chartered Institute of Waste Management (CIWM) commissioned a report on circular economy understanding and readiness across a wide range of stakeholders within the waste industry, gathering information through the use of a questionnaires completed by 612 respondents and 54 detailed interviews with industry leaders. The report found a lack of awareness and clarity of circular economy terminology and principles thereby impeding its advancement. Stakeholder engagement with an emphasis on communication, knowledge and skills as well as collaboration is underlined as key to circular economy progression. Like the UK, the Netherlands has a lot of organisations concerned and promoting CE such as The Circle Economy. A large amount of non-academic literature exists providing a lot of background information on CE and should not neglected.

2.10 Research gaps

The previous review of the CE literature has highlighted a number of research gaps which this research seeks to address through an in depth look at the metals sector. The identified research gaps can be summarised as follows:

Most studies are top-down implementation of CE, based on control-economies (Chertow, 2000; Geng and Cote, 2003; Geng et al., 2010; Shi et al., 2010: Zhang et al., 2010; Matthews and Tan, 2011; Bai et al. 2014). This research examines CE from a bottom-up approach and investigates the possible integration of both approaches. While sufficient research has been carried out on circular economy at the regional and industrial-park levels, how local firms and stakeholders interact, participate in a circular economy is not well documented. It is necessary to narrow the scope and provide insight into circular economy implementation at the firm level paying particular interest to the environmental, economic and policy implications.

There exists an emphasis on certain geographical locations in CE research. Research highlights that a lot of work has been carried out on China in particular where CE is considered as a national development plan. The growth in literature on CE in China coincides with the adoption of Circular economy law passed in 2009 by the Chinese government. CE in Europe has been mainly viewed as a strategy for implementation of environmental policies and waste management, but is gaining more popular. There is hence the need to better understand CE within European (UK) producers and consumers, especially given the important role producers and consumers play in influencing policies.

Little has been said about the socio-political implications and prospects of changing current produce-use-dispose practices within the current CE debates. Identification and classification of different drivers of, and barriers to, a circular supply chain, at a local level, from different stakeholder perspectives will help researchers in their empirical studies and investigations (Matthews and Tan, 2011). There is the need for more research rather than narrative to provide clear replicable examples of good practice, and for studies that a wide range of organisations and businesses can understand and apply.

Despite the recent increase of interest from academics and practitioners on CE, there limited work on the comparison between linear and circular systems using practical examples. In order to enable a shift in circular economy paradigm at firm level, it is important to understand supply chains and their life cycle assessment to properly compare different options that can be implemented within a circular economy process. There is also the need to widen the empirical evidence by developing additional studies related to circular supply chain adoption (Genovese et al., 2015; Nasir et al., 2017).

Furthermore, very few environmental indicators have been considered while exploring circular supply chains. The existing studies that have explored linear and circular supply chains have mainly concentrated on carbon (Global warming potential) as a measure of environmental viability (Nasir et al., 2017). This study goes beyond carbon and includes additional sustainability indicators such as Eutrophication, acidification, land use and cumulative energy demand while exploring the environmental dynamics of linear and circular supply chains.

2.11 Theoretical lens

Literature reveals the limited attempt to look at CE implementation through the lens of management theories. Institutional theory is employed in many instances to identify the drivers of circular supply chains (Zhu, Geng and Lai, 2010). Other studies suggest ecological modernization theory to explain the operational issues related to circular supply chains (Sarkis, Zhu and Lai, 2011). However, empirical work based on these theories is, to date, very limited. The stakeholder approach using stakeholder theory is taken in this study, and applied to CE to further aid its understanding. The methodological approach is detailed in chapter three (section 3.7).

Stakeholder theory is attributed to Freeman (1984) and has its roots in strategic management. As a theory of organisational management and business ethics, Stakeholder theory focuses on values and morals in organisational management (Freeman, 1984). Stakeholders can be defined as ‘‘those groups who can affect and/or are affected by the achievement of an organisation’s purpose’’ (Freeman, 1984). The theory has gained in importance over time, with important works by Clarkson (1994, 1995), Donaldson and Preston (1995), Mitchell et al. (1997), Rowley (1997) and Frooman (1999) allowing both greater theoretical depth and development (Mainardes et al., 2011).

Stakeholder theory is often explored from two viewpoints, namely, (1) the traditional restrictedly focused view which submits that the purpose of business is maximum wealth creation for stakeholders made up of investors, employees, suppliers and customers, and (2) the unconventional perspective widening the stakeholders to include other groups such as government bodies, political groups, trade unions & associations, communities, associated corporations, prospective employees, prospective customers, and the general public. Even competitors are sometimes counted as stakeholders (Genovese et al, 2013). Stakeholder theory proposes that externalities are produced that affect many parties (stakeholders), which could be both internal and external. Externalities often cause stakeholders to increase pressures on other stakeholders to reduce negative impacts and increase positive ones (Sarkis et al. (2011).

Stakeholder theory has been widely used within the supply chain context in order to explain specific stakeholder influences on green purchasing (Maignan and ¨McAlister, 2003); environmentally oriented reverse logistics (Sarkis et al., 2010); supply chain formation and configuration issues (Matos and Hall, 2007) and roles of various stakeholders within GSCM practices (de Brito et al., 2008).

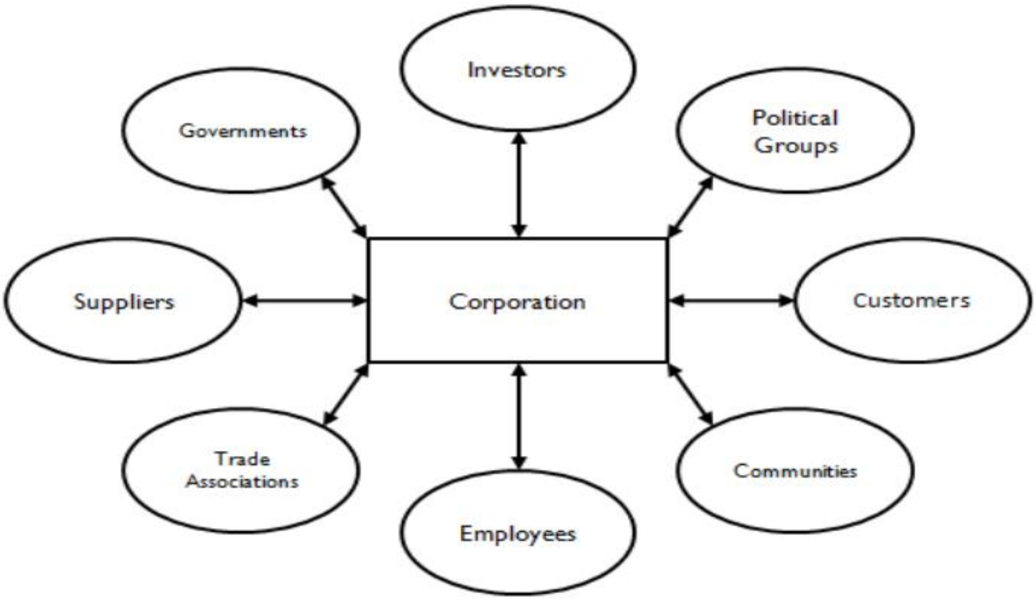

Figure 2.4: Conceptualisation of corporation-stakeholder relations. Adapted from Freeman (1984) and Donaldson and Preston (1995)

This study takes both the conventional viewpoint and considers the prospective broadening of stakeholder theory to identify and explain different key decision makers within the metals supply chain as well as their motivations. The Mitchell et al. (1997) concept of stakeholders' attributes of power is used to discuss the supply chain configuration of the metals sector and the interaction between public and private stakeholders within the context of this study. Additionally, the concept of contentious relationships between stakeholders and organisations proposed by Friedman and Miles, (2002) is also considered in this study in order to understand the stakeholders' interests and connections.

2.12 Chapter summary

Academic and wider literature relevant to this current research has been reviewed and critically analysed in this chapter. An academic review of the circular economy (CE) literature has been carried out, with emphasis being placed upon the origins of CE, its implementation across different levels (micro, meso and macro), drivers and barriers, and supply chain integration. A number of knowledge gaps in the academic literature have been drawn out and are used to formulate the specific objectives of the research.

Chapter three: Research methodology

3.1 Introduction

The achievement of the set objectives outlined in section 1.2 of chapter one requires a detailed methodology to ensure its realisation. This chapter therefore describes the research methodologies and approaches used in this work and highlight the procedures involved in carrying out the research for data collection and analysis purposes. Trochim and Donnelly (2001) reported that every research is governed by some form of assumptions regarding the way the universe is perceived and understood. These assumptions are informed by a number of factors including the focus area of the research (Trauth, 2001), the theme under investigation (Myers, 2013; Remenyi and Williams, 1998) and, to a certain extent, the disposition and point of view of the researcher (Fielden, 2003). In order to conduct a research in the hopes of finding answers to the research questions posed, the research is carried out using frameworks that are proven and well-established through the lens of research philosophies (Kumar, 2014). As such, the current work is informed by the research methodological framework based on "Research Onion" shown in Figure 3.1.

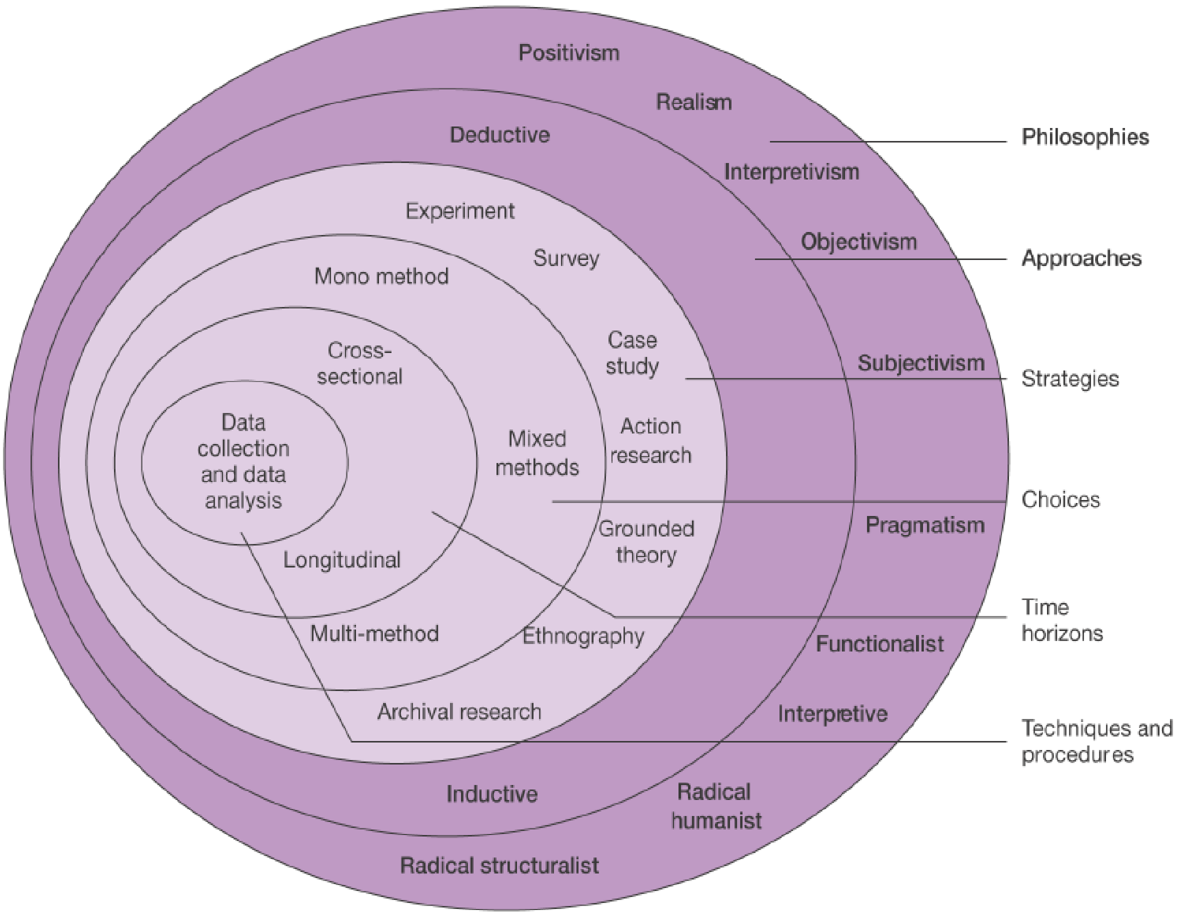

Figure 3.1: The Research Onion, adapted from (Sauders et al., 2003)

Based on the Research Onion shown in Figure 3.1 above, a description of the research philosophy and strategy that underpins the current research is provided in the sections that follow. It is not possible for the discussion on these themes to be exhausted in any particular study because of the wide nature of the topic, tainted with different views and opinions among researchers. To this end, only the aspects of the framework that are peculiar to this research are discussed. In order to put into perspective, the research methods and philosophies upon which the current builds upon, it is important to highlight the key research questions which this work seeks to provide answers to as described in the section that follows.

3.2 Research questions

The formulation and articulation of the research questions help bring into focus the scope of any research under consideration (Heinström, 2003; Kari, 2004). Based on the literature review presented in Chapter 2, the main research questions which are the focal points of this thesis are stated below:

- What are the environmental implications of circular production systems, across a number of sustainability metrics, of selected metals that have well-established primary and secondary production routes, within the metal and fabricated metal sector in comparison to a traditional linear production model?
- The circular economy paradigm is touted as a practical solution to the planet's emerging resource crunch given its capability to assist in stabilising key environmental issues through the decoupling of economic growth from resource consumption. Yet despite the assurances and advantages of its overall benefits, its embrace into the mainstream of decision making is still a difficult proposition. Accordingly, what are the drivers, barriers and main policy implications limiting the adoption of circular economy approaches, with a focus on the metals industry?
- How can findings from quantitative study (i.e. assessment of the environmental implications of circular production systems vs. linear production systems) be integrated with findings from qualitative study (i.e. the use of interviews to gain in-depth understanding of the drivers, barriers and stakeholder views), with the view to gain a better understanding of the transition towards a circular economy whilst laying a solid foundation for its acceptance and implementation?

To provide viable answers to the above listed research questions, based on the theoretical underpinning of circular economy, four case studies (based on product supply chains of representative metals within the metal and fabricated metal sector) are analysed.

3.2.1 Rationale for choosing the metal sector

As highlighted in Chapter one, the metal industry was chosen because of the special attention it received towards global decarbonisation efforts in the recently published Intergovernmental Panel on Climate Change Fifth Assessment Report (IPCC, 2014). Although the sector is responsible for high amount of GHG emissions into the environment, it also has the potential to reduce such emissions drastically using readily available technologies. Such reductions are made possible through the implementation of environmental regulations and policies (Serrenho et al., 2016) as well as sector-based emission reductions/preventions schemes using energy efficiency and conservations technologies (Koh et al., 2016).

In particular, within the metal industry globally, the rates at which metals are recycled have increased and the advent of new and advanced technologies has further reduced the need to extract virgin materials. In the steel industry for example strategies such as switching to more efficient production routes and improving the overall efficiency of existing manufacturing routes using best available technologies has contributed to drastic reduction in GHG emission (Napp et al., 2014). For instance, increased basic oxygen furnace (BOF) gas recovery especially in China and India and the use of coke dry quenching in China has led to improvements in emissions intensity in the steel industry (Akashi et al., 2011). In fact, Akashi et al. (2011) concluded that if existing and currently available GHG emission reduction technologies that cost below \$100/tCO_2 are introduced and implemented within the iron and steel industry by 2030, the projected emissions reduction potential in China and India will be 230 MtCO_2 and 110MtCO_2 respectively. This therefore demonstrate the potential of the metal sector in terms of emissions reduction and hence the focus on it in this thesis.

Despite the demonstrated role of technologies in GHG emission reduction, Allwood et al. (2010) reported such endeavours alone are not capable of delivering emissions savings required in the metal industry and that other strategies which borrows from the circular economy paradigm such as material efficiency, demand reduction reuse and recycling will also be required. This assertion is also echoed by (Gutowski et al., 2013a) and Gutowski et al. (2013b). Accordingly, the current work seeks to explore the factors responsible for the low integration of circular economy paradigm into the metal sector.

Circular patterns are not easy to implement in all sectors, as such the focus of the current work is on the metal sector due to the aforementioned factors. Other sectors including food processing industry, chemical industry, building and road construction and many more also possess a great deal of benefits which are not confined to energy usage but also water, materials, organic matter, emissions. For instance, Genovese et al. (2017) provided evidence and some applications of sustainable supply chain management and the transition towards a circular economy using the food and chemical industries as a case study. Specifically, they analysed the carbon dioxide emissions implications of the implementation of a circular supply chain using representative materials such as ferrous sulphate and waste cooking oil for the chemical and food industry respectively. They concluded that if the concept of circular economy is integrated with the core principles of green supply chain management, clear advantages can be provided especially from an environmental point of view. They however submitted that if such cases are analysed from an economic point of view, they may pose a great deal of challenges.

Dadhich et al., (2015) also analysed efforts towards developing sustainable supply chains in the UK construction industry through the lens of circular economy. As with other notable authors, they identified potential opportunities that can be garnered from the adoption of circular economy in the construction industry using plasterboard supply chain as a case study given that it is the most commonly used item within the UK construction industry. Although they identified potential intervention options that can aid the transitions towards a sustainable supply chain and circular economy, other useful insights that can be garnered by engaging key stakeholders was lacking. So far, no such detailed analysis based on circular economy with a specific focus on the metal sector using practical examples has been carried. The exploration of such area is an important to fill given its abundant potential as identified by the Intergovernmental Panel on Climate Change Fifth Assessment Report. It is anticipated that a deeper understanding of the transitioning towards a circular economy within the metal sector can help in shaping the understanding of key drivers, barriers and policy implications of other sectors. In doing so, the evaluations derived from the current research can be applied to other sectors especially as it pertains to infrastructure, stakeholders, policy making and overall benefits.

In the section that follows, an examination of the vital subject of research philosophy and paradigms with the view to offer a basis for further discussion of the research questions in terms of how viable answers is derived for them is presented. It provides a concise background to different epistemology stances to justify the approach selected for this study.

3.3 Research philosophy: epistemological and ontological considerations

Generally speaking, epistemology and ontology are the two key philosophical elements upon which every research is guided (Kumar, 2014). Epistemology is a philosophical stance used to gain an understanding and explanation of how we know what we know (Crotty, 1998). Maynard (1994) submitted that "epistemology provides a philosophical ground on which to decide what kinds of knowledge are possible and how adequacy and legitimacy of knowledge can be ensured". In order words, epistemology is concerned with how we know the world as well as the relationship between knowledge and the inquirer (Creswell and Clark, 2007). Against this backdrop, researchers are categorised in terms of their epistemological orientations as discussed in the subsection that follows.

3.3.1 Positivism

Positivism as a philosophy of inquiry emphasizes the use of empirical data and scientific methods such as experiments and statistics. It adheres to the view that natural empirical science is the sole source of true knowledge. Knowledge should be based on direct apprehension to reveal a true nature of how society operates. Positivism holds that the world consists of laws that are detectable. Positivist research is aimed at explaining and predicting, with generalisations made through statistical probability. In researches guided by positivism, the method of investigation is characterised by expressing research questions in the form of hypotheses and formulating appropriate equations to test the validity of the hypothesised phenomena (Bryman and Bell, 2015). Moreover, positivism requires the researcher's role to be limited to the collection of data, interpretation and maintain an objective minimal interaction with the research topic (Bryman and Bell, 2015). In other words, the researcher is independent of the study and there is limited room for human interest within the study.

Positivism is built upon precise methods, giving validity and objectivity to research (Creswell and Clark, 2007). The positivist approaches are often generalizable and replicable given that they based on a theoretical underpinning which to a great extent affects data collection and analysis (Sauders et al., 2003). Critics of positivism also argue that because it posits that everything can be measured and quantified, it tends to be inflexible, disregarding unexplained phenomena and eliminating lateral thinking (Creswell and Clark, 2007). Positivism requires objectivity and neutrality on the part of the researcher. However, in real life, it is difficult to detach human behaviour from emotion and there is therefore no guarantee that this will be the case all throughout the course of an inquiry.

3.3.2 Interpretivism

At the heart of interpretivism is the belief that social phenomena unlike physical objects cannot be accurately measured, quantified or predicted (Bryman and Bell, 2015). The social world is not governed by laws and regularities and as such methods used in natural science are not appropriate for social research. Quantifying the subjectivity and individuality of humans, their thoughts, beliefs, ideas and perceptions is very difficult. Interpretivism is of the view that the subject matter of natural sciences is inherently different from that of the social sciences. In contrast to the epistemological position of positivism, Interpretivism integrates human interest, intuition and reflection as crucial parts of the research process and investigation (Knight and Cross, 2012). There is room for great researcher bias while adopting interpretivism. The differences between natural sciences and social sciences needs to be respected and a strategy that considers and incorporates this is required (Bryman and Bell, 2015).

3.3.3 Pragmatism

Pragmatism is a philosophical rationale that allows the coupling of qualitative and quantitative methods of research into one study. Pragmatism is simply dealing with a situation or problem in a sensible manner suiting existing conditions rather than theoretical considerations. The best suited research methods naturally depend upon the research questions being addressed and pragmatism as an underlying philosophy for inquiry aids researchers in making a choice among varying models of inquiry (Morgan, 2007). Particular certain questions are best answered using quantitative methods, while others using qualitative analysis. The research question(s) are placed at the centre of endeavours of pragmatic researchers (Johnson and Onwuegbuzie, 2004).

3.4 Research strategy

Research strategy refers to the method of data collection and analyses adopted in the current work and are described briefly in the subsections that follow.

3.4.1 Qualitative and Quantitative Methods

Quantitative research refers to the measure, appraisal, evaluation and counting of things (Berg-Weger et al., 2001). The strategy is in tune with positivist epistemological orientation because it adopts a scientific approach to the identification and formulation of the research question within a well-established framework (Creswell and Clark, 2007). Under this form of research strategy, research questions are usually phrased based on estimation models in the form equations which are derived from known principles. Quantitative research has an emphasis on the collection of numerical data aimed at testing specified theories (Bryman and Bell, 2015). It allows causal relationships between variables to be established whilst providing vital insights into the interrelationships that could exist between very many variables of interest and facilitates the understanding the links that exist between such variables (Adelopo, 2010). The validity of this approach could be tested using a number means including statistical analysis or even mathematical equations with the view to find answers to the research questions at hand. Quantitative research is also referred to the term “deductive” approach to research (Creswell and Clark, 2007).

On the other hand, qualitative research encourages the discovery of how social meaning is constructed and stresses the relationship between the researcher and the topic under investigation (Denzin and Lincoln, 1998). It has an inductive view of the relationship between research and theory generation with the aim of understanding certain social phenomena through the careful analysis of interpretations of research participants (Denzin and Lincoln, 1998). By adopting a qualitative approach to research problem, the research questions and methods can lead to the establishment of theory which can in turn lead to the identification of behavioural pattern (Adelopo, 2010). Qualitative research captures the social dynamics of firms, institutions and their internal constituents, the stakeholders and the socio-environmental systems. It entails the use of data collection and analysis approaches that are particularly suitable for the investigation of a social actor within a social setting, whilst recognising human dynamics and vagaries at every stage of the entire research process (Adelopo, 2010). In-depth interviews, observations, ethnography, action research and focus groups are used in qualitative research. Given that qualitative research approach allows for the exploration of profound analysis of a phenomenon, it can assist in establishing intuitive meanings derived from spoken and unspoken responses whilst facilitating the first-hand experience and interaction with the subject of the investigation. This attributes of qualitative research approach helps in addressing the use of representative variables upon which quantitative research approach is based (Adelopo, 2010).

Despite the many advantages offered by qualitative approach to research, it is tainted with a number of well recognised disadvantages such as the problem pertaining to generalisation and of replicability of the methods given that phenomenon such as feelings, emotions, views and perception differs from one individual to another. In some instances, getting unrestricted access to respondents can be a very difficult proposition. Ethical considerations can sometimes pose problems in qualitative research (Adelopo, 2010; Johnson and Onwuegbuzie, 2004).

3.4.2 Inductive vs deductive approach

Representing the most common view of the relationship between theory and research, deductive approach involves the deduction of a hypothesis by the inquirer that is then scrutinised empirically. On the contrary, drawing generalisable inferences out of observations is the main objective of the inductive approach, the outcome of research being theory building (Bryman and Bell, 2015).

3.4.3 Mixed methods

Mixed methods model of research inquiry is a philosophy underpinning the combination of qualitative and quantitative models of research, drawing on the strengths of each method so that knowledge is increased in a more useful manner than one or the other could provide alone (Creswell and Clark, 2007). Mixed methods rejects the incompatibility thesis that claimed different methods of analysis are not compatible with each other and hence not be used together (Howe, 1988). The potential to avoid some of the problems associated with conventional research methods is a clear benefit of adopting mixed methods research. For example, the failure of qualitative methods to move from the specific to generality or dehumanisation of the subject matter by quantitative methods. Mixed methods gives researchers the opportunity to utilize a variety and combination of techniques to solve research questions without being restricted (Creswell and Clark, 2007; Johnson and Onwuegbuzie, 2004).

3.4.4 Research philosophy and paradigm used in this research

Judging from the central aim of this research, a detailed numerical analysis of data will be involved given that it entails a comparison between linear and circular economy based on primary and secondary sources of metals within a LCA framework. At the same time, a qualitative analysis of data will be involved because of the views and perceptions of key stakeholders towards the transition to circular economy. Against this backdrop, this study therefore adopts a systematic application of both qualitative and quantitative methods. Mixed methods allows the pragmatic combination of the quantitative analysis of linear and circular supply chains with the qualitative understanding of different motivations and perspective that shape the decisions between linear and circular economy and dictate actions taken. This use of mixed mode research approach will facilitate a better understanding of the motivations behind the actions of the stakeholders especially as it pertains to their understanding and perception regarding the move towards circular economy.

In this work, the key use of quantitative methods is to assess the environmental implications of circular production systems based on multiple sustainability indicators (e.g. carbon emissions, resource use and waste recovered) when compared to a traditional linear production paradigm through a life cycle assessment. The qualitative aspects of the research on the other hand helps in gaining in-depth understanding of drivers and barriers to circular economy adoption as well as the behaviour, experience and attitude of the stakeholders towards implementation of circular economy through the use interviews analysed using thematic content analysis. By integrating both quantitative and qualitative research strategies, it helps in the explanation and interpretation of themes derived from both approaches, allowing both technical viability and wider acceptability of the phenomenon under investigation to be explored, leading to the provision of viable answers to the research questions posed. In order to provide answers to the research questions, a procedural framework through which the phenomenon underpinning the current work can be considered is depicted in Figure 3.2

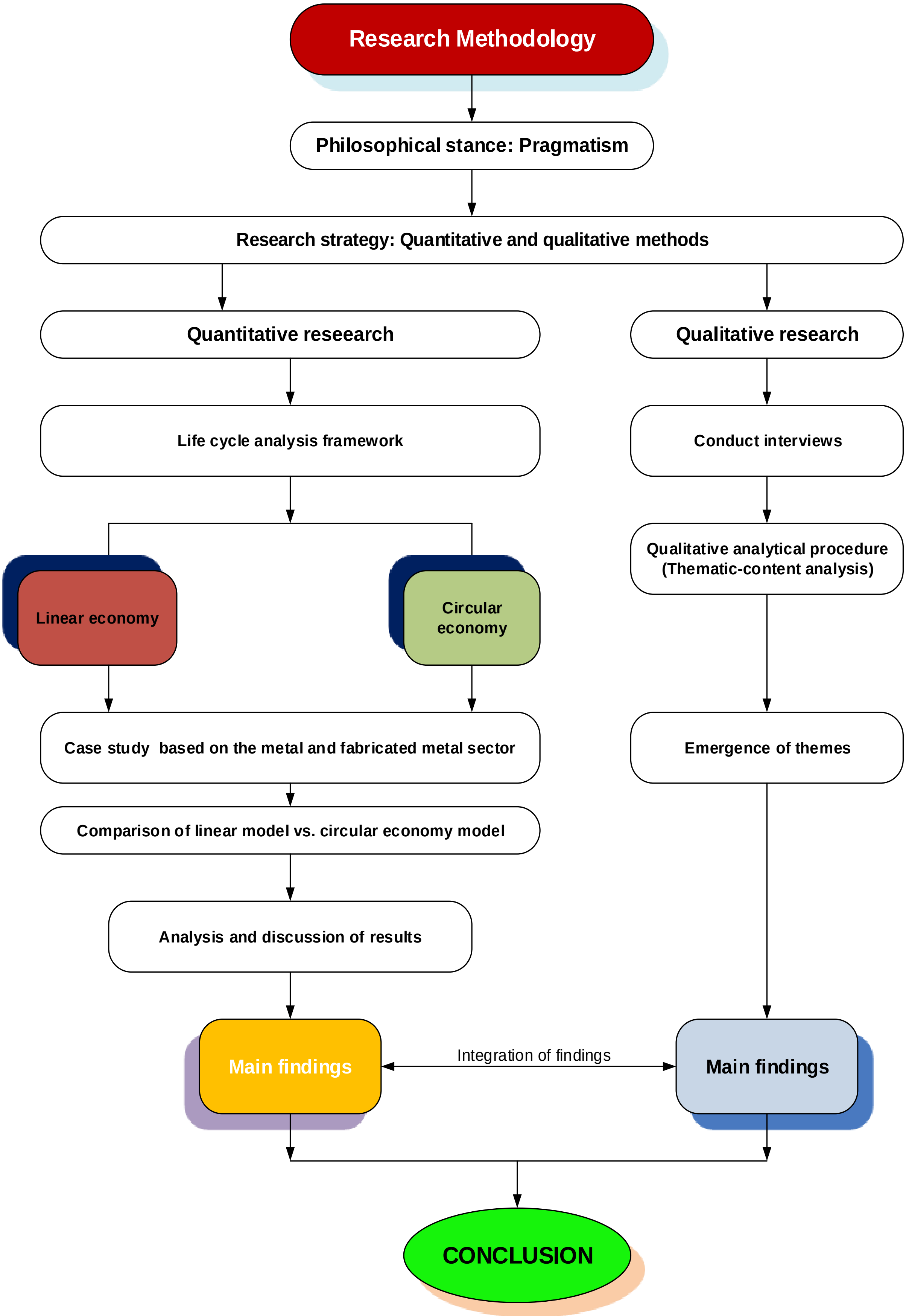

Figure 3.2: Overall research methodology and procedural framework

3.5 Data collection and analysis

3.5.1 Quantitative aspects of this research- Life Cycle Assessment

Life cycle assessment (LCA) is a technique based on life cycle thinking and it can be adopted for the systematic evaluation of the environmental aspects of a product or service system through all stages of its life cycle" (UNEP/SETAC Life Cycle Initiative, 2012). It is used for sustainability assessment of products and/or process systems as well as in environmental analysis supporting clean production. The adoption of LCA framework allows for the identification of pathways to production processes associated with high energy and resource usage, pollution and emissions of greenhouse gases, for which suitable basket of intervention options and strategies can be devised and implemented in order to address them (Acquaye et al., 2011b; Ibn-Mohammed et al., 2014). LCA tries to identify, characterise and measure different potential environmental impacts during each stage of the life cycle of a product or process. It enables its users, who could be the public (e.g. government agencies), or private users (e.g. product designers) companies, and individuals the opportunity to consider the whole environment while making better long term choices. LCA also helps anticipate and avoid shifting problems from one life cycle stage, one geographical region to another and from one impact category to another (UNEP/SETAC Life Cycle Initiative, 2012).

LCA is guided by a number of standards from the International Organisation for Standardisation (ISO). For instance, the ISO 14000 series of environmental management standards developed by the ISO in collaboration with other organisations notably United National Environment Programme (UNEP) and the Society for Environmental Toxicology and Chemistry (SETAC), provide guidelines and a framework for environmental LCA. The principles, framework, requirements and guidelines for conducting environmental LCA are particularly provided by ISO 14040 and ISO 14044 (ISO, 2006). Both ISO 14040 and ISO 14044 include the definition of the goal and scope of the LCA, the life cycle inventory analysis (LCI) phase, the life cycle impact assessment (LCIA) phase, the life cycle interpretation phase, reporting and critical review of the LCA, limitations of the LCA, the relationship between the LCA phases, and conditions for use of value choices and optional elements (ISO, 2006). The standards have been revised over time to their current versions of ISO 14040 and 14044. Figure 3.3 provides the overall framework for LCA.

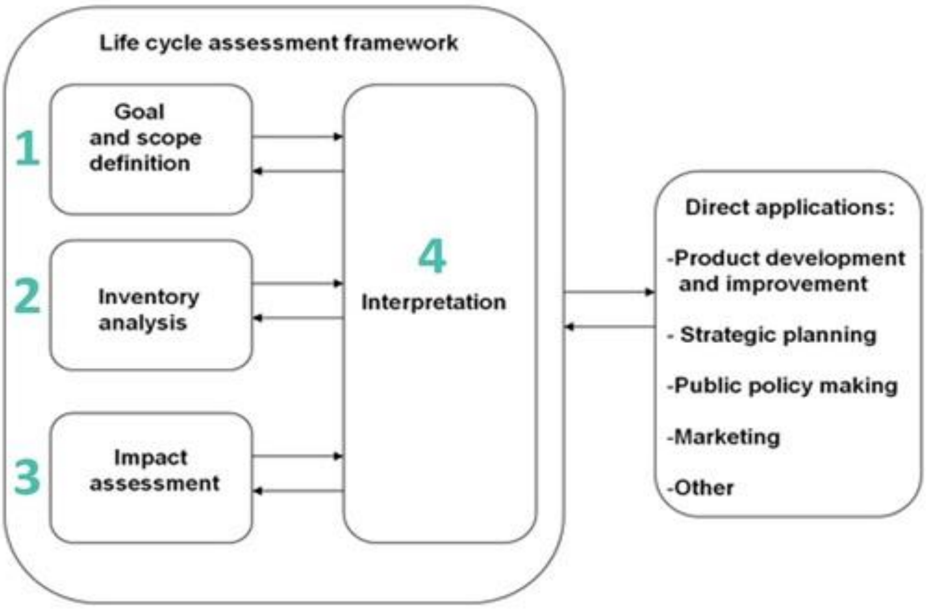

Figure 3.3: Life cycle assessment framework. Adapted from ISO (2006).

3.5.2 Phases of LCA framework

As indicated in Figure 3.3, there are four main phases involved in an LCA framework and each phase is described in the succeeding paragraphs.

(a) Goal and Scope Definition

The purpose and methodology of the LCA is outlined in the goal and scope phase. It is the stage where the purpose of the study is defined and one of the most important phases, often quite subjective. Questions such as the type of data needed and available need to consider. It is important to consider the intended application of the study, the reasons for carrying out the study and the target audience of the analysis. In this phase, the Functional unit, assumptions, limitations, data requirements are established and the system boundary is set. The functional unit is a measure of the function of the product, process or system being studied and serves as a reference to which inputs and outputs can be associated. The System boundary determines which unit processes are included and excluded in the study. Determining the system boundary of a study often relies on subjective choice.

(b) Inventory Analysis

Life cycle inventory (LCI) is an approach used to estimate resource consumption, waste flows and emissions that happen as a result of a products life cycle or that can be attributed to it (Ibn-Mohammed et al., 2013; Rebitzer et al., 2004). It is a simple accounting of all flows in and out of the system under consideration. These flows could be raw materials, water, energy of various types, and emissions to land, water and air. LCI can be consequently complex, including multiple unit processes within a supply chain such as raw material extraction, transportation and numerous primary and secondary production processes, etc.

Life cycle inventory analysis may come across simple in its definition but in practice is not always straight forward. For instance, data quality, geographical variations, choice of technology are a few of the practical issues that may arise and have to be addressed in conducting the inventory analysis (Dixit, 2010; Dixit et al., 2012; Ibn-Mohammed et al., 2013). The amount of resources consumed and emissions produced per functional unit across the entire system is the final output of the LCI analysis. It can be used in comparative analysis, scenario analysis as well as identifying potential policy interventions (Rebitzer et al., 2004). A schematic representation of lifecycle inventory is depicted in Figure 3.4.

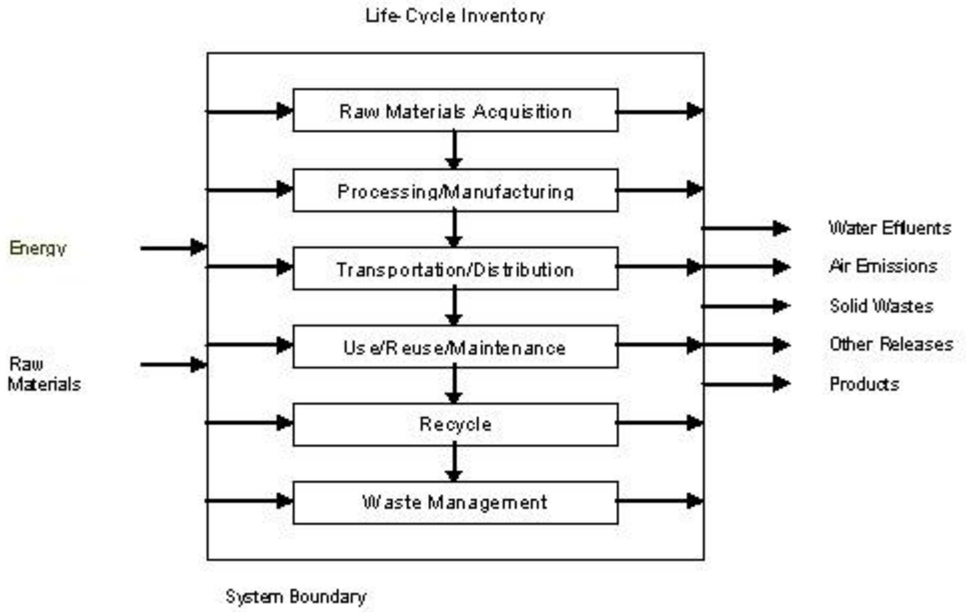

Figure 3.4: Schematic life cycle of a generic product. Adapted from ISO (2006).

(c) Impact Assessment

The impact assessment phase of LCA involves relating inventory identified to impact on humans, the environment and resources. It is the phase where resource consumption and emissions data collected from the LCI are analysed interpreted. The aim of LCIA is to convert data from LCI into simpler indicators. An LCIA often involves four steps: classification, characterization, normalisation and weighting, the first two are mandatory while the latter two are optional (ISO, 2006). Classification requires that all materials or processes are grouped based on their effects on the environment. Characterization involves the multiplication of all materials or processes by a factor reflecting their environmental impact contribution. Normalisation is done by scaling the data to a reference factor or value. Weighting is a process of combining of all impact categories together, based on value judgement, to come up with one single score or value. Weighting is one of the most controversial LCIA steps.

(d) Interpretation of results

The systematic identification, quantification and evaluation of results from the inventory analysis and/or impact assessments is referred to as life cycle interpretation of results. Life cycle interpretation is performed so as to decide the level of confidence in the results with the view to effectively communicate them to the intended audience such as policy and decision makers. Life cycle interpretation of results must meet two purposes before it can be adjudged satisfactory (ISO, 2006):

- Results should be analysed, conclusions reached, limitations explained and recommendations provided on the basis of the results of the previous phases of the LCA and the results of the analysis should be reported in a transparent manner
- The results should be presented promptly in an understandable, complete, and consistent manner, in accordance with the goal and scope of the study

LCIA permits significant issues relating the results of the LCI to be identified. This phase also allows conclusions and recommendations to be made in line with the defined goal and scope of the study. In order to actually carry out the LCA study, there are a number of techniques utilised within the LCA community and are described briefly in the section that follows.

3.5.3 LCA Modelling techniques

(a) Process lifecycle assessment methodology

Often referred to as Bottom-up models, the traditional process LCA technique for the quantification of energy consumption and environmental impacts involves adding the various energy outflows associated the production processes of a product. However, as the supply chain becomes more complex, data acquisition becomes increasingly difficult and expensive.

As one attains the stage where data availability becomes limited, the system boundary is drawn. All processes beyond this point are discarded and this is commonly termed as truncation error (Acquaye et al., 2011a). Crawford (2008) found that process LCA can neglect up to 87% of a products embodied energy. Therefore, using process analysis tends to underestimate processes in the life-cycle of a product and their contribution to overall energy demand and emissions. Figure 3.5 depicts the schematic representation of the process-based LCA. As shown, the calculation process works in a backward fashion within the upstream of main process commencing with the targeted material as a final product.

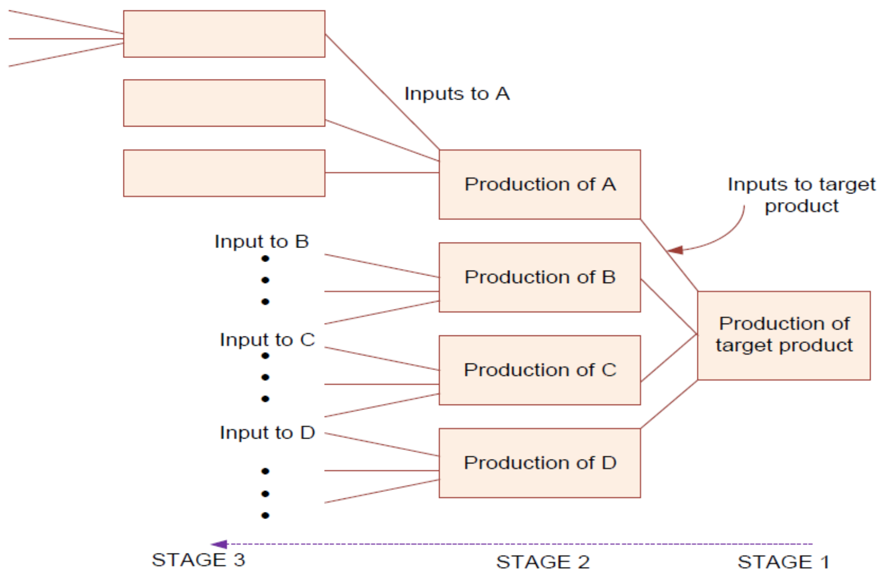

Figure 3.5: Schematic illustration of process-based LCA. Adapted from Ibn-Mohammed (2017).

(b) Input-output lifecycle assessment methodology

The environmental input-output (EIO) is another technique that is employed for the estimation of embodied emission associated with a product or process. The EIO makes use of matrices of all financial transactions between sectors of the economy and each sector is ascribed an energy intensity (Acquaye and Duffy, 2010). The EIO adopts country and/or regional input–output data linked to averaged emissions from a given economic sector to compute environmental impacts, yielding detailed result with enhanced visibility. The method offers comprehensiveness and completeness because it captures nearly the entire system boundary (Dixit, 2010; Ibn-Mohammed et al., 2013) by taking into account the whole activities across the supply chain of a process or product including those accrued by indirect suppliers, allowing the tracking of the complete range of inputs to a process, thus avoids systems boundary issues that characterises the process-based approach (Acquaye and Duffy, 2010; Ibn-Mohammed et al., 2014). The price of a product and the energy intensity of its sector are used to calculate life cycle costs and impacts. However, the technique suffers from aggregation error. This is because it assigns the same energy intensity to all products within the same sector. Other well-known limitations of the EIO approach to LCA is detailed by Miller and Blair (2009).

(c) Hybrid lifecycle assessment methodology

Both process-based LCA with EIO LCA (Acquaye and Duffy, 2010; Ibn-Mohammed, 2017; Ibn-Mohammed et al., 2014) can be combined into a consistent framework known as hybrid LCA (Acquaye et al., 2011b; Ibn-Mohammed et al., 2016; Ibn-Mohammed et al., 2017) yielding much more robust results by expanding the system boundary and complies with ISO standards. By integrating the benefits of both process and I-O analysis, fundamental errors and limitations linked to each method can be reduced, improving accuracy and precisions. Hybrid analysis is systemically complete because it makes use of process data together with input-output data to fill in the gaps, thus making use of the most accurate figures for the identified processes (Acquaye et al., 2011b; Koh et al., 2013; Wiedmann et al., 2011).

3.5.4 Life cycle assessment application in this study

One of main aims of this research is to analyse and compare the environmental impacts associated with the supply chain of selected metals namely copper, lead, nickel, steel and polystyrene, based on two categorisation: (a) one obtained from the recycling of scrap (old scrap) for instance from electronic and electric waste in the form of old batteries (in line with circular economy paradigm) (b) one that uses virgin materials derived from activities such as mining or other production methods (in accordance with the current production route known as linear supply chain). In each case, the products being analysed and compared serve the same function and can hardly be differentiated. Supply chains can be better understood through life cycle assessment because it enables the identification of production processes such as energy, resource and pollution which businesses can then use for decision making and trade-off analysis.

In this study, the process LCA methodology is chosen and is performed from cradle to gate. Process LCA despite its shortcomings such as being time consuming, complex, subjective and truncation error allows for the specificity of individual inputs within a defined system boundary and leads to accurate determination of environmental impacts (Lenzen and Crawford, 2009). Process LCA allows the specified analysis and comparisons of two different supply chains without the need for aggregate data, too many assumptions and generalisations, across the product lifecycle including extraction of resources from the earth, agricultural activities and forestry etc. (the cradle) to transportation, refining, processing, and manufacture up to the factory gate when the product is ready to leave for distribution to consumers (Rebitzer et al., 2004). In this work, the focus is on a number of sustainability indicators based on the CML method (Guinée, 2002). The CML method was chosen because it is one of the most common indicator methodologies, providing midpoint indicators that offer more detail and traceability. The endpoint indicators on the other hand look at environmental impact at the end of the cause-effect chain, making it easier to picture, not requiring extensive environmental knowledge.

3.5.5 Data source: Ecoinvent database

Emissions data for primary and secondary steel, nickel lead and copper were sourced from secondary means through the Ecoinvent database. Ecoinvent is recognised as the largest and most consistent LCI database available, providing access to data on unit process exchanges (UPR) as well as system process (LCI). Ecoinvent (2017) comprises of datasets covering most industries and is frequently updated with new available data. The database has been in use for over 20 for LCA data compilation and this is the reason why it has been used in this study

The following exact information is retrieved from the Ecoinvent database:

- Unit process data that provides the quantity and unit of measure of processes
- The impact categories in the CML Baseline 2001 methodology which include global warming (GWP 100) (GWP), acidification (AP), eutrophication (EP), ozone layer depletion (ODP), photochemical oxidation (POCP), human toxicity (HTP), fresh water aquatic ecotoxicity (FAETP), marine aquatic ecotoxicity (MAETP), and terrestrial ecotoxicity (TAETP).
- Eco-indicator 99 that comprise ecosystem quality, human health and resources. Eco-indicator 99 ecosystem quality comprise: acidification, eutrophication and land occupation. Eco-indicator 99 Human health comprises: carcinogenics, climate change,

ionising radiation, ozone layer depletion and respiratory effects. Eco-indicator 99 ecosystem resources comprise: fossil fuels, and mineral extraction.

The preceding section 3.5 has detailed the quantitative aspects of this research based on life cycle assessment framework. In the section that follows, a description of the qualitative aspects of this research detailing the procedure and technique for data collection and analysis is provided.

3.6 Qualitative aspects: interviews with stakeholders

Interviews are one of the most familiar approaches to collecting qualitative data and are the approach taken to collect data in this research. An Interview has the capacity to produce useful data to examine a wide variety of perspectives and create a complete outlook of the topic under investigation. The type of interview used was semi-structured interviews as is briefly described in the subsection that follows:

3.6.1 Semi structured interviews

Qualitative research projects often use semi-structured interviews as the only data source. Semi-structured interviews are usually pre-determined that provide uniformity, consisting of open-ended questions, used to guide the conversation and prompt discussion between the researcher and the participant. It is common for the interviews to be conducted once, ranging from between 30 minutes to several hours depending on how interesting the conversation is to both the researcher and the participant. Additional questions usually occur as a result of the dialogue between the researcher and participant (DiCicco-Bloom and Crabtree, 2006). Participants get the freedom to express their views in their own words through the interview process and as a result reliable and comparable data can be accumulated. Semi-structured interviews aim to make the interview process resemble a normal conversation between two parties but where a number of predetermined topics are the focus of the discussion. A major limitation pertains to the fact that it can be time consuming.

3.6.2 Participant recruitment/Sampling method

Purposive sampling was the main sampling strategy used in this research. Purposive sampling involves deliberate search for participants with particular features and experience. Purposive sampling is commonly used in qualitative research as a way to make a selection based a characteristic or group of characteristics. The recruitment tools used were email invitations, letter invitations and direct visitation to prospective participants. Snowball technique was also utilised in the form of referrals from existing participants and word-of-mouth approaches. This technique offers a sample that could otherwise be inaccessible and helps with the difficult problem of obtaining respondents where high levels of trust are needed to make initial contact. The stakeholders identified consisted of local council, scrap metal handlers, metal producers, consumers/households, industry experts, households, regulators (Environment agency) and NGOs. These were considered to be most suitable for this PhD study.

3.6.3 Thematic content analysis or template analysis

Given that the perception and views of the subjects regarding the subject under investigation (i.e. transition towards circular economy) is vital to the overall validity of the current research, it is pertinent to adopt an analytical procedure that allows for: (i) the use of a standard framework, structure, or theoretical precepts from which themes can be recognised from the qualitative data; (ii) the emergence of themes in a natural fashion, which further enriches the findings from the qualitative data set. This will provide additional insight and enhance the identification of other salient issues that were not initially foreseen as part of the overall interview process. In doing so, the outcomes would allow robust answers to be provided to the overall research question which the current work seeks to address. Accordingly, the current work adopts a qualitative analytical framework known as thematic content or template analysis (Braun and Clarke, 2006; Cassell et al., 2006; McGrath and Pistrang, 2007).

The term 'template analysis' refers to a certain way of analysing qualitative data thematically. The data involved is usually in the form transcripts of interviews, observed discussions or classes, focus groups, soundtrack from video diaries etc. Template analysis is used to reduce large amounts of unstructured text to that which is relevant and manageable for the evaluation and comparison of the perspectives of the different participant groups regarding their experience. The conducted interviews were recorded and augmented with note taking before the final transcription. Copies of interview transcripts were shared with participants to check for errors and to make amendments where necessary. The qualitative data was analysed using template analysis where specific codes or templates were produced. The themes were identified from the interviews based on research objectives and aims. The codes allow a general overview of the data.

In the section that follows, a brief description of the management theorems to guide the current research is provided.

3.7 Stakeholders' Theory as a theoretical lens

Literature reveals the limited attempt to look at CE implementation through the lens of management theories. Institutional theory is employed in many instances to identify the drivers of circular supply chains (Zhu et al., 2010). Other studies suggest ecological modernization theory to explain the operational issues related to circular supply chains (Sarkis et al., 2011).

In his work, Freeman (2010) described stakeholder theory as a conceptual framework adopted in business ethics and organisational management which deals with the moral and ethical values within the overall management structure of a given business or an organisation. Across the years, the stakeholder theory has been improved and its justification has been well received in management literature given its accuracy of its description, its instrumental power and normative validity (Donaldson and Preston, 1995). In recent years, the development of stakeholder theory has increased due to its emphasis on the explanation and prediction of the overall function of an organisation especially as it pertains to the relationships and influences existing in its environment (Rowley, 1997).

Stakeholder theory generally starts based on the assumption that are an integral and explicit part of conducting business by calling for the manager's articulation regarding the shared sense of the value they establish and what it offers the key stakeholders (Freeman et al., 2004). Based on the concept of stakeholder theory, managers are pushed to be clear about their manner of carrying out business in terms of the kind of relationship that is sought with the key stakeholders with the view to deliver on the overall purpose of the business (Freeman et al., 2004). Given this features of the stakeholder theory, it was employed as one of the theoretical lens upon which the current work is guided. In the section that follows, a description of empirical validity and the approaches taken towards the validation of the current work is presented.

Stakeholder theory is often explored from two viewpoints, namely, (1) the traditional restrictedly focused view which submits that the purpose of business is maximum wealth creation for stakeholders made up of investors, employees, suppliers and customers, and (2) the unconventional perspective widening the stakeholders to include other groups such as government bodies, political groups, trade unions & associations, communities, associated corporations, prospective employees, prospective customers, and the general public. Even competitors are sometimes counted as stakeholders (Genovese et al, 2013).

Stakeholder theory proposes that externalities are produced that affect many parties (stakeholders), which could be both internal and external. Externalities often cause stakeholders to increase pressures on other stakeholders to reduce negative impacts and increase positive ones (Sarkis et al. (2011).

Stakeholder theory has been widely used within the supply chain context in order to explain specific stakeholder influences on green purchasing (Maignan and ¨McAlister, 2003); environmentally oriented reverse logistics (Sarkis et al., 2010); supply chain formation and configuration issues (Matos and Hall, 2007) and roles of various stakeholders within GSCM practices (de Brito et al., 2008).

This study takes both the conventional viewpoint and considers the prospective broadening of stakeholder theory to identify and explain different key decision makers within the metals supply chain as well as their motivations. The Mitchell et al. (1997) concept of stakeholders' attributes of power is used to discuss the supply chain configuration of the metals sector and the interaction between public and private stakeholders within the context of this study. Additionally, the concept of contentious relationships between stakeholders and organisations proposed by Friedman and Miles, (2002) is also considered in this study in order to understand the stakeholders' interests and connections.

3.8 Empirical validity

For a piece of research to be adjudged satisfactory as a contribution to knowledge, the conclusions drawn from the study must be validated (Amaratunga et al., 2002). Ascertaining validity is key because it is the quality upon which the study is considered effective, reliable, and, in some instances generalizable (Easterbrook et al., 2008). The criteria by which a research's validity is judged depend on its philosophical stance. There are four criteria for validity (Amaratunga et al., 2002; Easterbrook et al., 2008; Knight and Cross, 2012; Kumar, 2014):

(1) **Construct validity** pertains to whether the theoretical constructs are interpreted and measured accurately. It is identified through the accurate design and use of data collection techniques for the specific concepts under investigation

(2) **Internal validity** pertains to the study design, and most importantly establishes whether the results realised are in tune with the data used. It is required for demonstrating any causal relationships in which certain conditions are believed to lead to other conditions.

(3) **External validity** pertains to whether claims for the generality of the results are justified. It is the degree to which the findings of the research can be generalised.

(4) **Reliability pertains** to whether the study produces similar results if other researchers repeat the procedure (i.e. the degree to which the research can be repeated, with the same results).

To ensure that research findings are reliable and credible, a research design should seek to address specific validity threats (Maxwell, 2012). Through the explicit acknowledgment of the validity threat, the researcher demonstrate that he/she is conscious of the potential flaws and have adopted the appropriate steps to lessen their effects (Easterbrook et al., 2008). In the context of the current work, the LCA outputs were validated based on the narratives in the extant literature. Regarding the qualitative aspects of this research, subjective assessment through expert interviews with professionals who are familiar with the overall mode of operation of circular economy was adopted.

3.9 Ethics

This study has ethical approval from the Sheffield University Management School ethics committee. This is particularly important given that the current research entails gathering of information about perceptions of key stakeholders through interviewing.

3.10 Limitation of methods

The current work employs mixed-mode research approach to investigate the drivers, barriers and policy implications of circular economy, using the metal industry as a case study. The justification for choosing the metal sector has already been highlighted as indicated in section 3.2.1. The quantitative aspect of the current work employs the computational techniques of LCA to demonstrate and highlight the merits of transitioning from a linear economy to a circular economy. On the other hand, the qualitative aspects of the research seek to gather thoughts and opinions from experts and key stakeholders within the metal industry regarding the transition from linear to circular economy. The qualitative aspect also includes establishing the extent to which such transitions are feasible whilst analysing potential drivers and barriers. This was largely achieved by interviewing key stakeholders within the sector. In this sense, the interviews conducted aim to provide valuable insights related to the ease and challenges of transitioning to a circular economy. The interviews aimed to not only provide the qualitative primary data that is vital to further evaluate the findings from the quantitative (i.e. LCA aspect) but also aid the dissemination of the final findings of the overall research aim and objectives.

Despite the mixed-mode approach taken to address the problem in the current work, there are a number of limitations of the methods adopted. For instance, the sustainability indicators adopted for the LCA aspect are limited in scope in that they do not capture some important indicators (e.g. social considerations) that could be used to shape the understanding of the concept of circular economy beyond environmental issues alone. Accordingly, the use of LCA-specific indicators may not be a sufficient strategy, prompting the need for CE-specific indicators which may form the basis of a new certification scheme towards evaluating the circularity of a process, activity or even a product.

From the qualitative aspect of the work, not all important and key stakeholders were reached or agreed to participate with the view to ascertain their perception towards a circular economy in the metal sector. For example, the current work provides a very accurate measure in terms of views and perception of a given set of specific stakeholder, but do not allow for the expansion of the interview to cover a wider spectrum of stakeholders who may provide a very different picture or show resistance or lack of understanding to the concept of circular economy. Further limitations based on the methodological framework adopted in this research are highlighted in Chapter Six, 6.4.5. See page 161.

3.11 Chapter summary

The overall research methodology and philosophy used in this research was presented in this chapter. These comprise two inter-related studies:

1. A quantitative analytical framework which entails the use of environmental lifecycle assessment to assess the environmental implications of circular production systems in terms of sustainability indicators (carbon emissions, resource use and waste recovered) when compared to a traditional linear production paradigm through a life cycle assessment.
2. A qualitative framework based on interviews with stakeholder to obtain gain in-depth understanding of drivers and barriers to circular economy adoption as well as stakeholder behaviour, experience and attitude towards implementation through the use interviews and thematic content analysis.

In chapter four, the results of the LCA work within CE framework is provided followed by discussion and analysis of interviews conducted in chapter five.

Chapter 4: Life cycle assessment and its application to linear and circular supply chains

4.1 Introduction

Metals contribute to almost all products that are now essential to people's daily life. Metals such as copper, steel, aluminium, nickel etc. are primary components used in phones, computers and laptops, food containers, and are also constituents of the transport system in the form of cars, buses or the rail network and even in aeroplanes. Metals are therefore vital and indispensable in current daily life. With population growth and increased demand, there is a need to transition from the current linear production and consumption system to one more sustainable. Over recent time, circular economy has emerged as an alternative to this linear system (Genovese et al, 2015). Circular economy has been gaining attention in industry as well as academia. Circular economy can be seen as an economic paradigm in which resources are used for as long as possible, extracting maximum value, stressing recycling benefits of old, waste and by-products (Jacobsen 2006), promoting growth at the same time decoupling from rapidly growing natural resources use. Metals are endlessly recyclable. There is no limit to the number of times the metals can be used, reused and recycled, thus offering a great opportunity for adopting circular economy principles. While a high percentage of metals are already being recycled and reused, there is a still a large number of metals that are not been used properly. A number still goes to landfill and incineration. Why is this so? In this research, we investigate the environmental justification of applying circular economy to the metals industry. We also look at barriers to doing so from a multi-stakeholder perspective. This study examines four metals namely copper, lead, nickel and steel with the view to use them to compare both linear and circular economy approaches across a number of sustainability metrics. The principles of LCA described in chapter three are adopted for the analysis given that supply chains can be better understood through technique.

In the sections that follow, a detailed analysis of the case studies using LCA is presented.

4.2 Case studies considered based on representative metals within the metal sector

4.2.1 Copper

Copper is primarily produced from ores found in the earth's crust. It is characterised as being malleable, ductile, and has extremely good heat and electricity conductivity. Copper is also corrosion resistant and is only third behind iron and aluminium in terms of major industrial metal consumption. Chile in South America has the largest copper ore deposits in the world and in 2014 had a mine output of 5.75 million tonnes copper, accounting for almost one-third of global copper mine production. Major producers also include China, the US, Peru, Russia, Zambia, Australia, Canada and the Congo. It is estimated that around one-third of global copper demand is met by secondary production through new and old scrap recycling (ICSG, 2015).

The main consumers of refined copper are the construction and consumer products industries, accounting for an estimated 58% of world copper demand. Electrical and electronic products, transport and industrial machinery are the next biggest users. Copper is key component for electric wires, pipes, flat-rolled products for heat exchangers or architecture, and medical devices.

4.2.1.1 Primary (linear) production of copper

There are a couple of ways to produce copper from virgin copper ores depending on the type of copper material. It could be either the Pyrometallurgical or Hydrometallurgical process. Primary production of copper in this case study is done through the Pyrometallurgical process. Figure 4.1 illustrates the process of primary copper production described below.

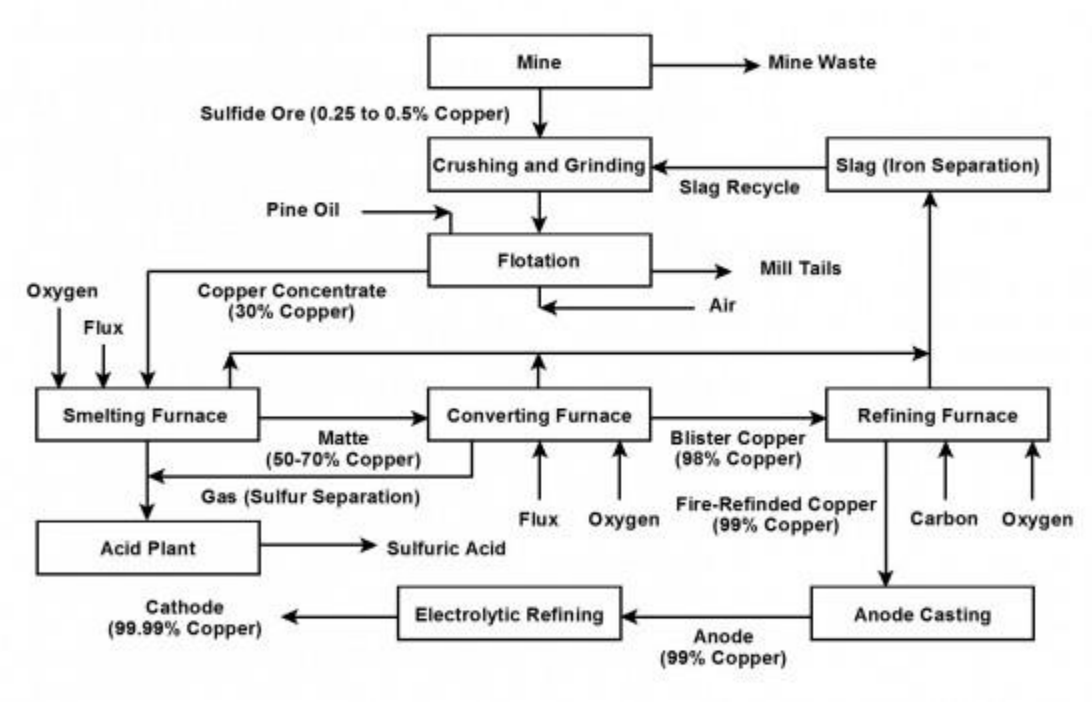

Figure 4.1: Flow chart of primary (linear) copper production. (Source: Copper alliance UK)

The steps are outlined below:

- Mining of copper: using high tech machinery at mines to drill and blast deep holes into the earth
- Blasted rock containing ores are hauled to crushers
- Crusher (mills): crushes the rock ore to small more manageable sizes
- Conveyor: conveys the crushed ores to the grinder
- Grinder: these are giant rotating mills that grind the small ore to powder
- Separation: floatation, mixing the right amount of water, chemicals and air. The chemical reaction leads the copper to float to the top of the solution in the form of copper concentrate, a liquid material
- Filtering; pressed filtered and dried, resulting into a powder like material, a bit like ground coffee.
- The coffee like powder is heated in blast furnace at very high temperatures that causes it to melt, forming a molten metal referred to as matte copper. Several other by-products such as sulphuric acid are produced as well as silica and iron.
- The matte copper is further refined through a series of furnaces to remove remaining impurities. The result is a highly pure copper that is poured into large plates anodes and allowed to cool
- Electrolysis: the anodes are submerged in an electrolytic solution of sulphuric acid and copper sulphate. This produces currents and causes the removal of even more impurities. Valuable impurities such as gold and silver are also recovered from this process. The end product is 99.99% pure copper cathodes. The cathodes are then sold off to producers that manufacture a large number of goods.

The hydrometallurgical route includes leaching of the copper oxide ore with sulfuric acid. This produces a solution from which copper metal can be recovered through an electro winning process.

4.2.1.2 Secondary (circular) production of copper from electronic and electric scrap

Secondary copper production starts with copper scrap. It therefore avoids the energy and resource intensive stage of mining that occurs in the linear primary production of copper highlighted previously. The scrap can be in the form of copper scrap such as wire scrap, plumbing scrap; alloy scrap such as bronze, brass, gunmetal and copper-iron scrap such as telephone scrap, circuit elements and switchboard units (electronic and electric scrap) (EEE, 2013). The scrap is collected, inspected, sorted and graded. The scrap can be classified into high and low grade scrap. The scrap enters the production process depending on their chemical copper content at either the smelting stage or fire refining stage. Pure copper scrap goes straight to moulding and casting and does not go through the cathode production stages. Slags rich in copper such as refining slags are also used as raw materials in secondary copper production and are usually recirculated at previous production stages, particularly the converting, or the smelting stage.

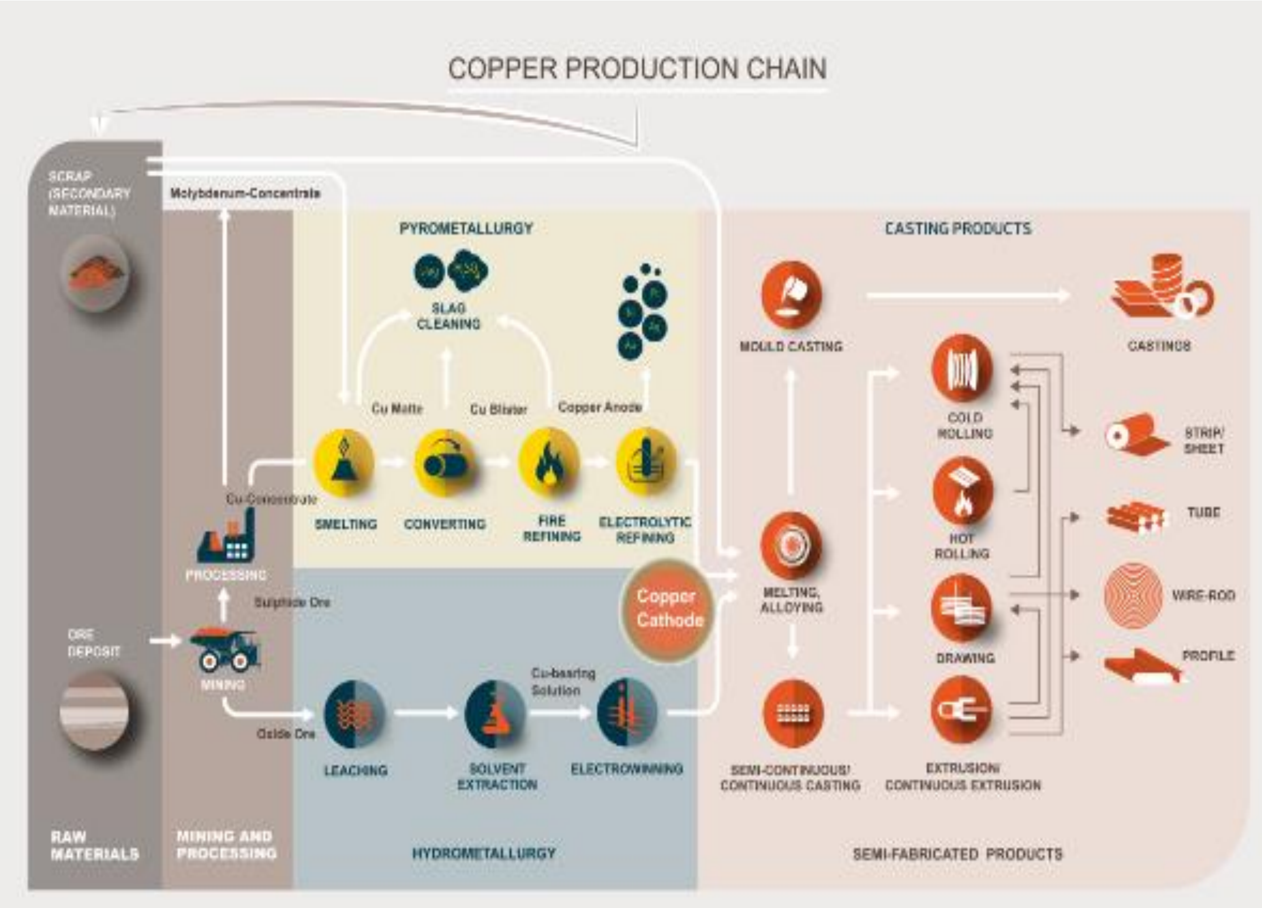

Figure 4.2: Primary and secondary copper production chain (Source: European Copper institute, 2011)

The remaining production process is similar to that of the Pyrometallurgical process of primary copper production. The various stages allow for the optimal removal of constituents, impurities and the recovery of metals. Figure 4.2 illustrates both primary and secondary copper production. It shows the two copper production methods; Pyrometallurgical and Hydrometallurgical process. This is study only looks at the chain up to the copper cathode stage highlighted in red in the middle of the diagram.

4.2.1.3 Comparative analysis of linear vs circular economy model of copper production

Using 3 life cycle impact assessment methods namely: Impact-oriented characterisation (CML 2001), Cumulative Energy Demand (CED), Eco-indicator 99 (Egalitarian perspective), the environmental impact of primary and secondary copper production is examined. The first results compare the carbon (climate change) emissions implications of producing copper cathodes using virgin copper ores through a linear production system to the production of copper cathodes using copper recycled scrap through a circular supply chain based on secondary sources derived from electronic and electric scrap recycling. Figure 4.3 illustrates this comparison.

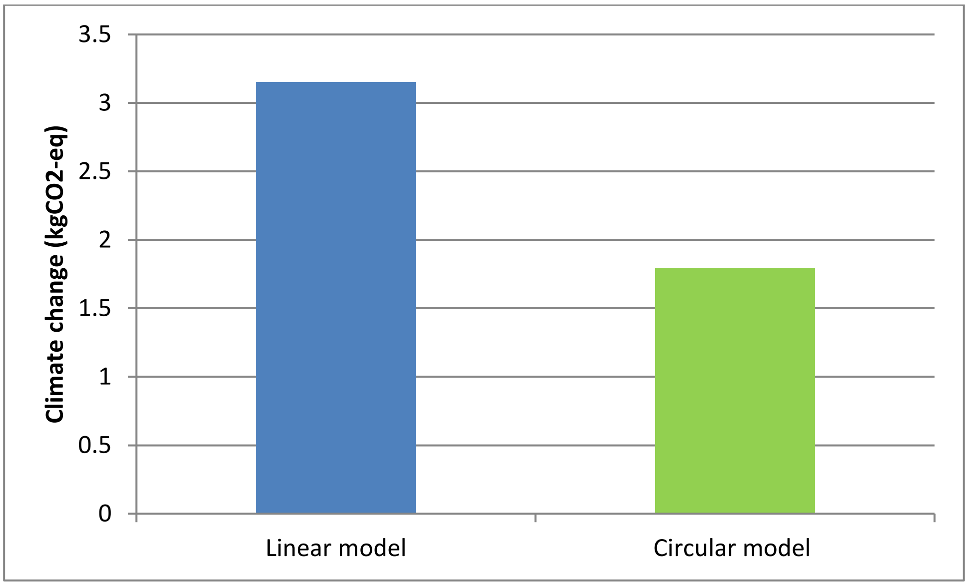

Figure 4.3: Comparative carbon emissions of linear vs circular economy model

The result shows that the carbon emissions from the supply chain of primary copper are 3.1532 $kgCO_2$-eq while that of recycled copper scrap is 1.7949 $kgCO_2$-eq. It indicates that copper produced using recycled electronic scrap through a circular supply chain contributes significantly lower carbon emissions than that of the produced using virgin copper ores from mining through a linear production system. Similarly comparing linear copper production with copper production from very high quality processed copper scrap shows increased benefits in going circular as depicted in the figure 4.3.1. it can be clearly seen that the higher the quality of scrap, the less the environmental impact in production. It should be noted that the circular model 1 does not include the collection, sorting, cleaning and refining of the scrap copper.

It can be observed from Figure 4.4 (a) that copper mining and beneficiation is the main carbon hotspot of primary copper production. It contributes 51 % of total carbon emissions. Copper mining and beneficiation includes not only the mining but also the mining infrastructure, through floatation and disposal of overburden and tailings and their associated carbon emissions. Heavy fuel oil used in the industrial furnace is also a significant carbon hotspot at 18%. This is closely followed by copper refining process with emissions of 0.4927 $kgCO_2$-eq, contributing 16 % of total carbon emissions. The copper refining process consists of the ore mining, the leaching and extraction, the electro winning and the disposal of the leaching residues.

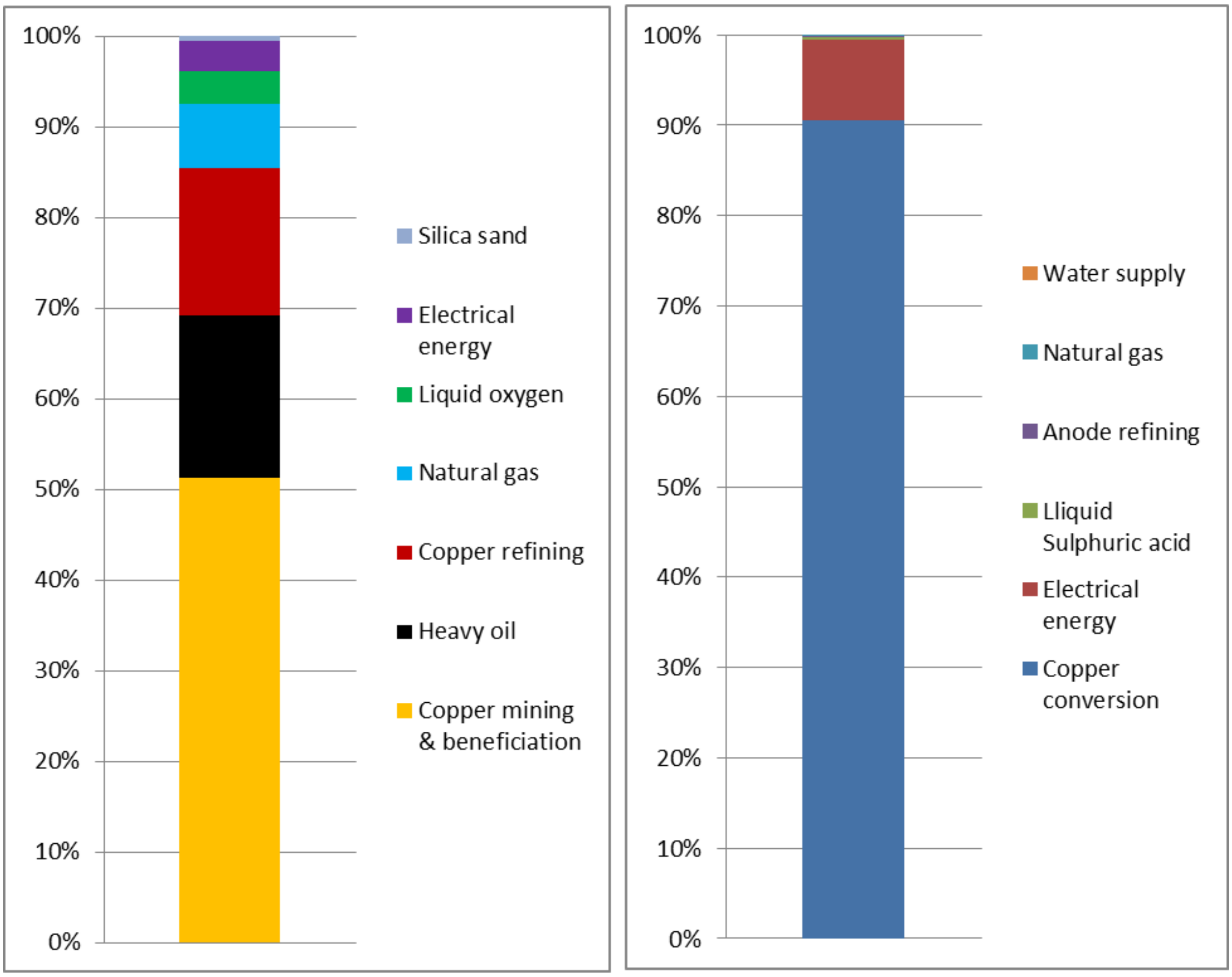

Figure 4.4: Breakdown of carbon emissions for (a) linear economy model; (b) circular model

Similarly, looking at the breakdown of emissions from secondary copper production from electronic and electric scrap, it is found that multi-stage electric waste conversion in to copper is the main carbon hotspot contributing 91% of all emissions. Electricity is the second most significant hotspot accounting for 9% at 0.0092 kgCO_2-eq. All other processes contribute less than a percent.

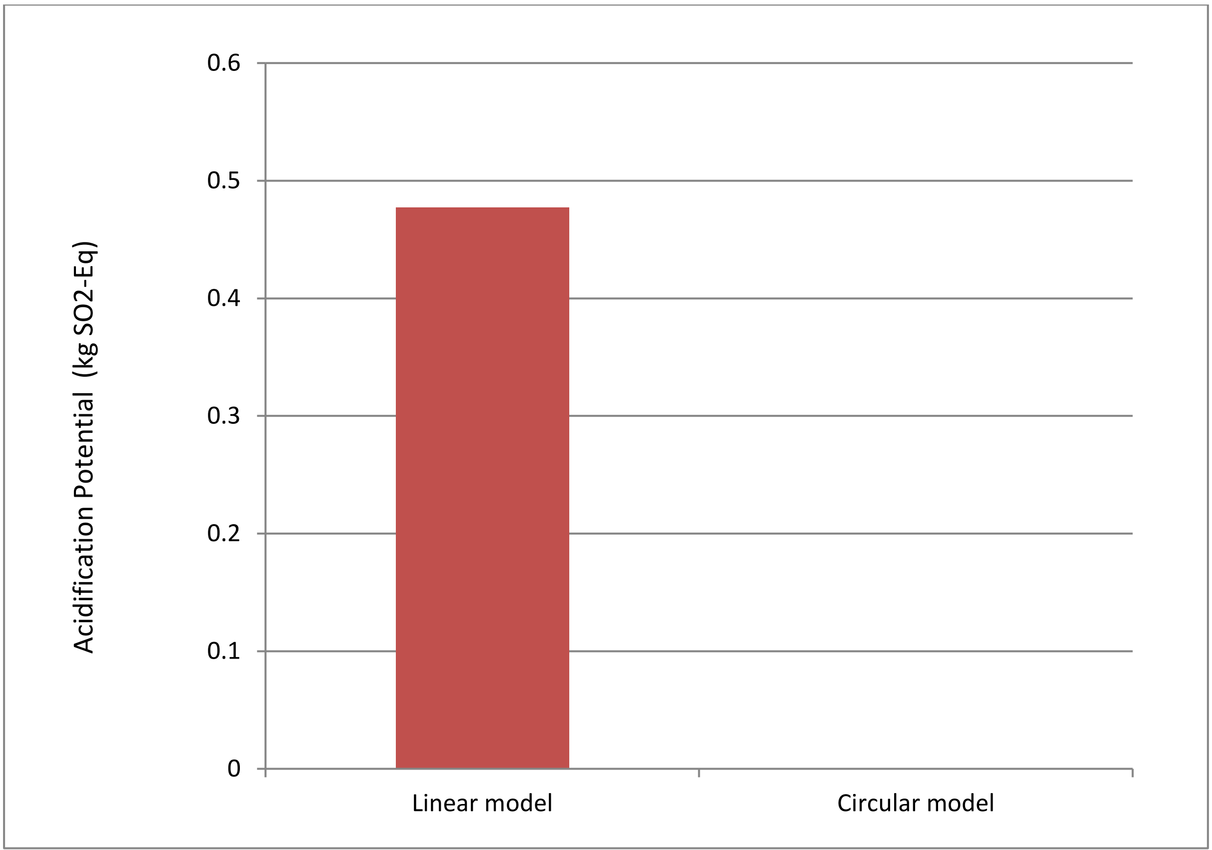

Figure 4.5: Acidification potential of 1 kg primary vs secondary copper production

In terms of acidification potential, recycled copper also performs better. It causes less acidification potential at 0.0002 kg SO_2-eq, which is less than 0.05 % of the acidification potential brought about by primary copper production at 0.478 kg SO_2-eq.

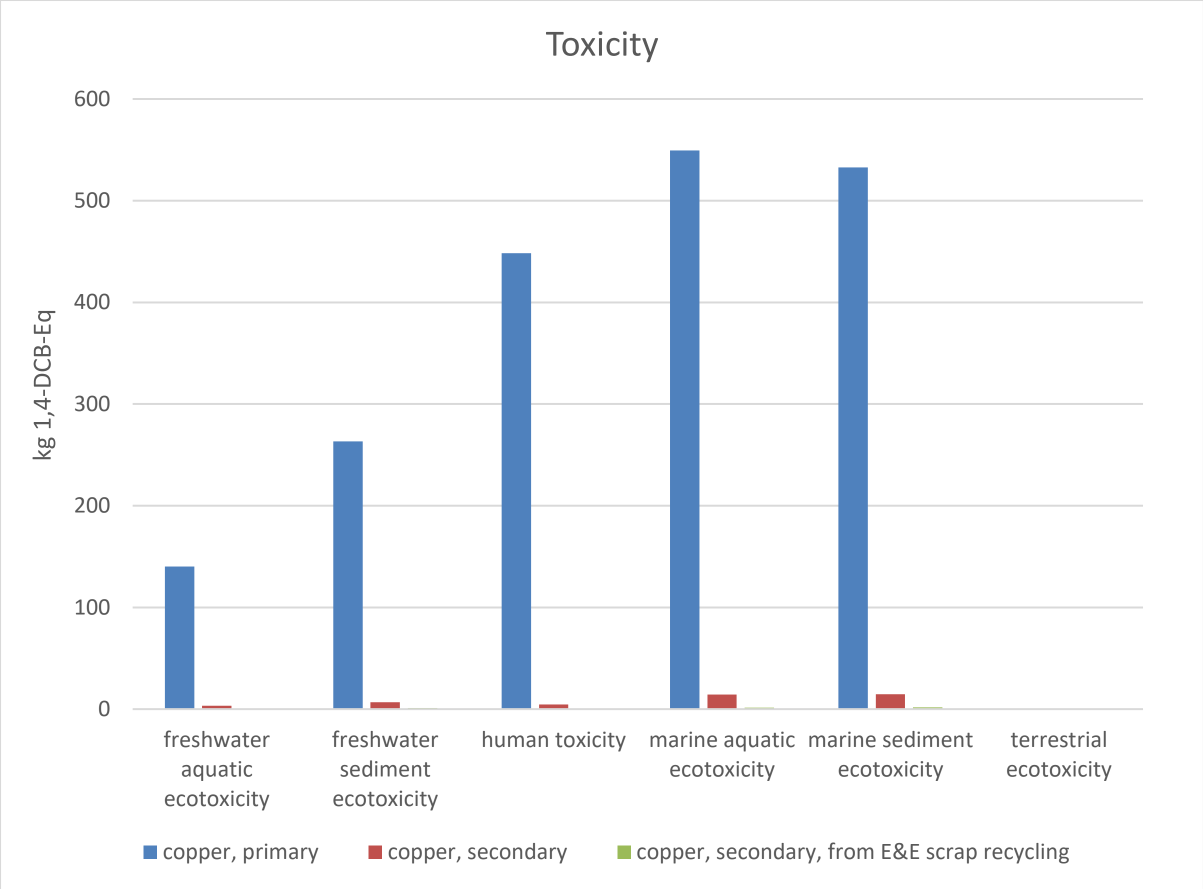

Figure 4.6: Results of footprint of primary and secondary copper production across six variants of toxicity.

Fig 4.6 presents the comparative analysis of copper mined from ore and copper recycled from electronic and electric scrap across six toxicity indicators based on the CML 2001 method (Guinee, 2002). It can be seen that secondary copper performs in a more environmentally friendly manner in all of the toxicity indicators.

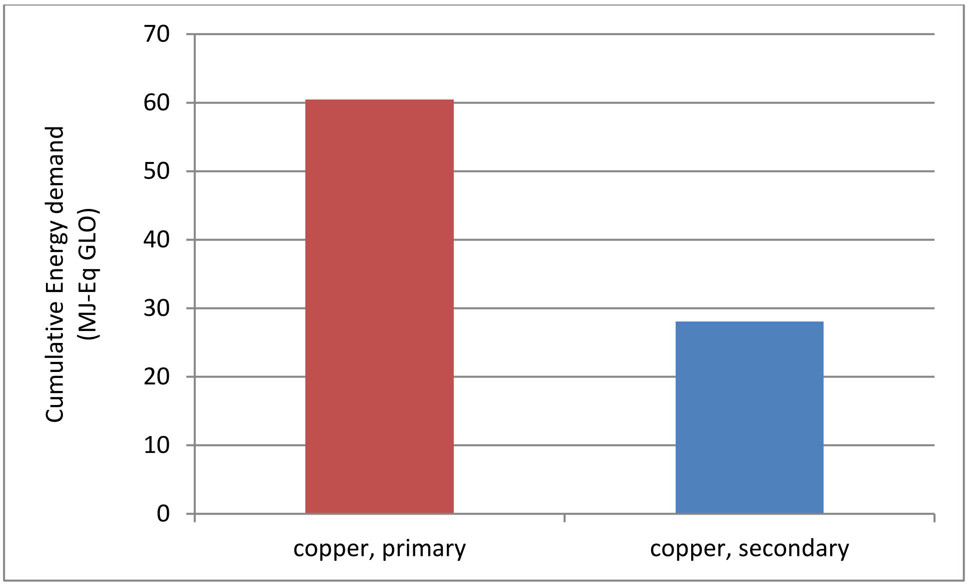

Figure 4.7: Cumulative energy demand for 1 kg of primary and secondary copper.

Figure 4.7 above clearly shows that less than half of the energy demand for linear copper production is needed in the circular production of copper from secondary material.

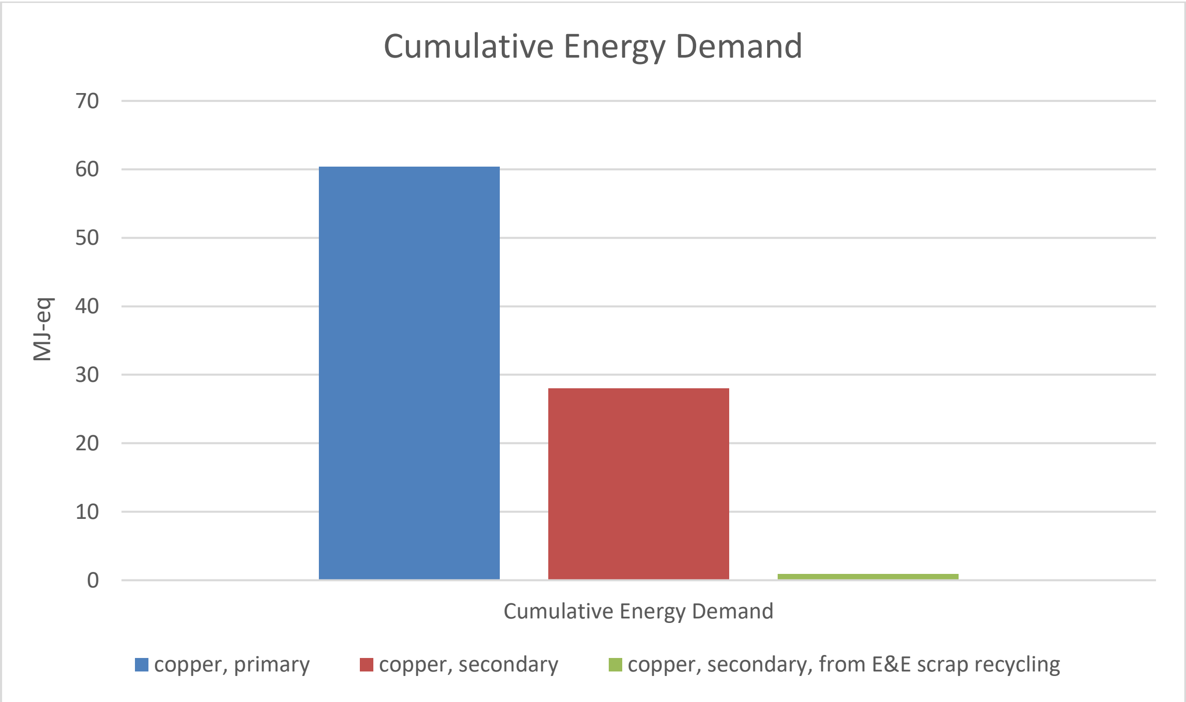

Figure 4.8: Cumulative energy demand for 1 kg of primary and two secondary copper routes.

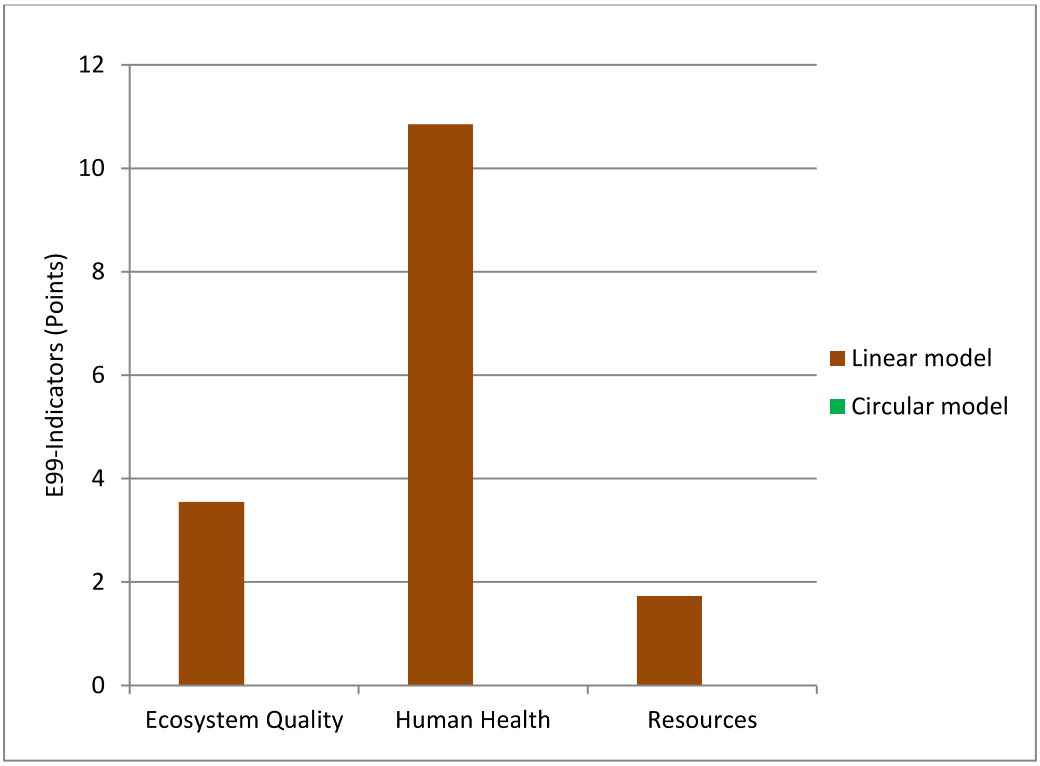

Figure 4.9: Eco-indicator 99 results for 1 kg of primary and secondary copper.

Correspondingly, in terms of Eco-indicator 99 impacts that comprise ecosystem quality, human health and resources, primary copper also has significantly more impacts on the environment compared to secondary copper.

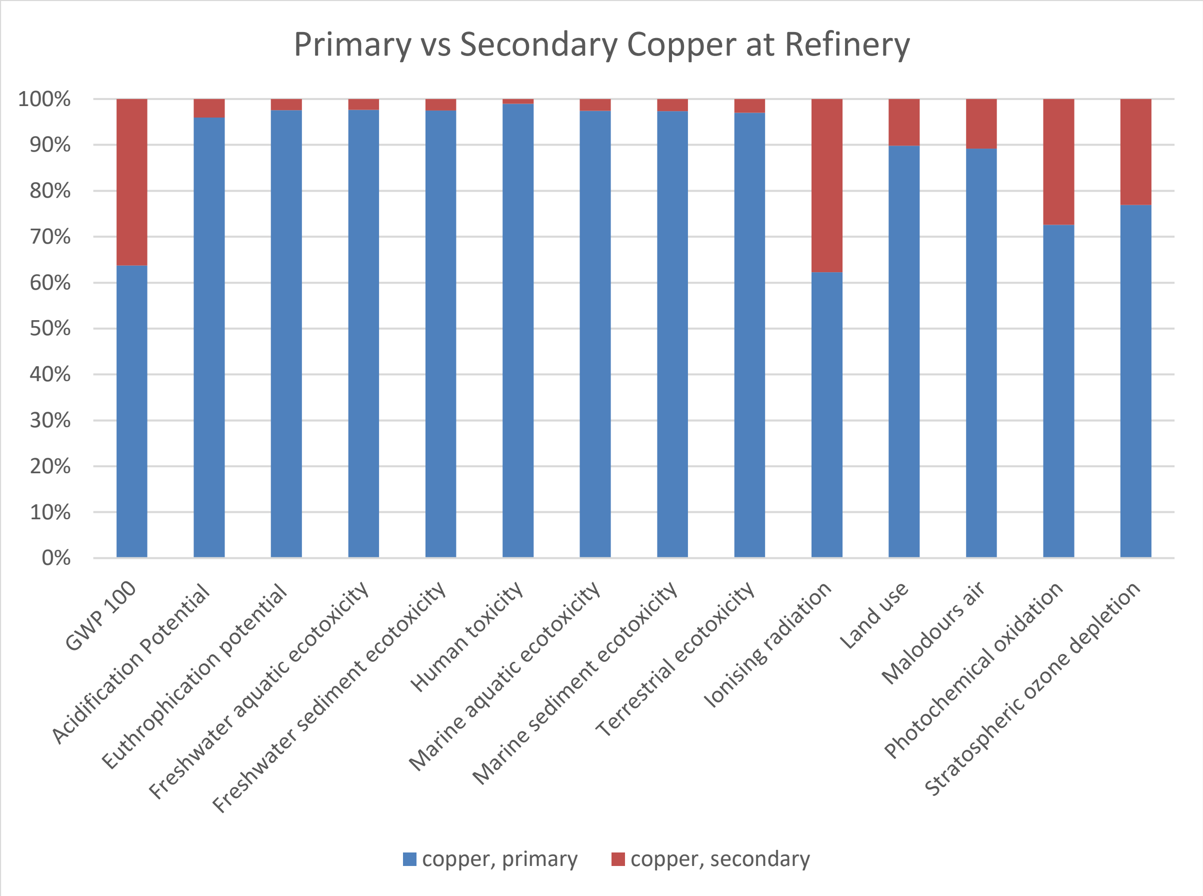

Figure 4.10: primary vs secondary copper across multiple indicators

Figure 4.9 shows the comparison between primary and secondary copper production across multiple impact categories. All impact indicators have been normalised and the total of each impacts equal to a 100%. From the diagram it is evident that secondary production via a circular route of recycling and reuse is less harmful and more beneficial from an environmental point of view.

4.2.1.4 Component level analysis of environmental profile of primary and secondary copper

Figures 4.9 and 4.10 show the environmental profiles of 1 kg of primary and secondary copper respectively. All impact indicators have been normalised and the total of each impacts equal to a 100%. The environmental profiles show the breakdown of all the environmental indicators considered in this comparative study. In Figure 4.9 copper beneficiation is the most significant contributor in primary copper production for all indicators except cumulative energy demand. It contributed acidification (73%), eutrophication (85%), fresh water aquatic ecotoxicity (83%), fresh water sediment ecotoxicity (83%), human toxicity (79%), land use (75%), marine aquatic ecotoxicity (83%), marine sediment ecotoxicity (83%), and terrestrial ecotoxicity (84%). Copper beneficiation lowest contributions were to stratospheric ozone depletion (44%), and terrestrial ecotoxicity (49%). The environmental profile of primary copper suggests that the extraction of copper is not an environmentally benign activity. From mining and milling through to hydro- and pryro-metallurgical processing to refining, the extraction of copper can have significant adverse impacts on air quality, surface and groundwater quality, and the land (Aigbedion and Iyayi, 2007; Bridge, 2000; G. Georgopoulos et al., 2001).

Similar to the GWP 100 breakdown above, copper refining is also a major emissions hotspot, closely following copper beneficiation. It contributed land use (21%), photochemical oxidation (20%), ionising radiation (19%), acidification (19%), eutrophication (15%), fresh water aquatic ecotoxicity (15%), fresh water sediment ecotoxicity (15%), human toxicity (18%), marine aquatic ecotoxicity (15%), marine sediment ecotoxicity (15%), and terrestrial ecotoxicity (10%).The non-ferrous metal smelter is the only contributor to cumulative energy demand. It consists of facilities for roasting, electrolysis and for the blast furnace and converter processes. In terms of Eco-indicator 99 impacts that comprise ecosystem quality, human health and resources, copper mining and beneficiation is also the highest contributor.

From Figure 4.10 multi stage electric waste conversion in to copper is the most significant contributor for all indicators in secondary copper production. It contributed fresh water aquatic ecotoxicity (99%), fresh water sediment ecotoxicity (99%), marine aquatic ecotoxicity (99%), marine sediment ecotoxicity (99%), photochemical oxidation (97%), human toxicity (91%), stratospheric ozone depletion (90%), acidification (72%), and terrestrial ecotoxicity (71%). The lowest contribution of Multi stage electric waste conversion into copper was to eutrophication (51%). In terms of Eco-indicator 99 impacts, multi stage electric waste conversion into copper is also the highest contributor. It contributed ecosystem quality (97%), human health (79%) and resources (83%). Multi stage electric waste conversion into copper also contributed to 77% of cumulative energy demand followed by electricity that constituted 22%.

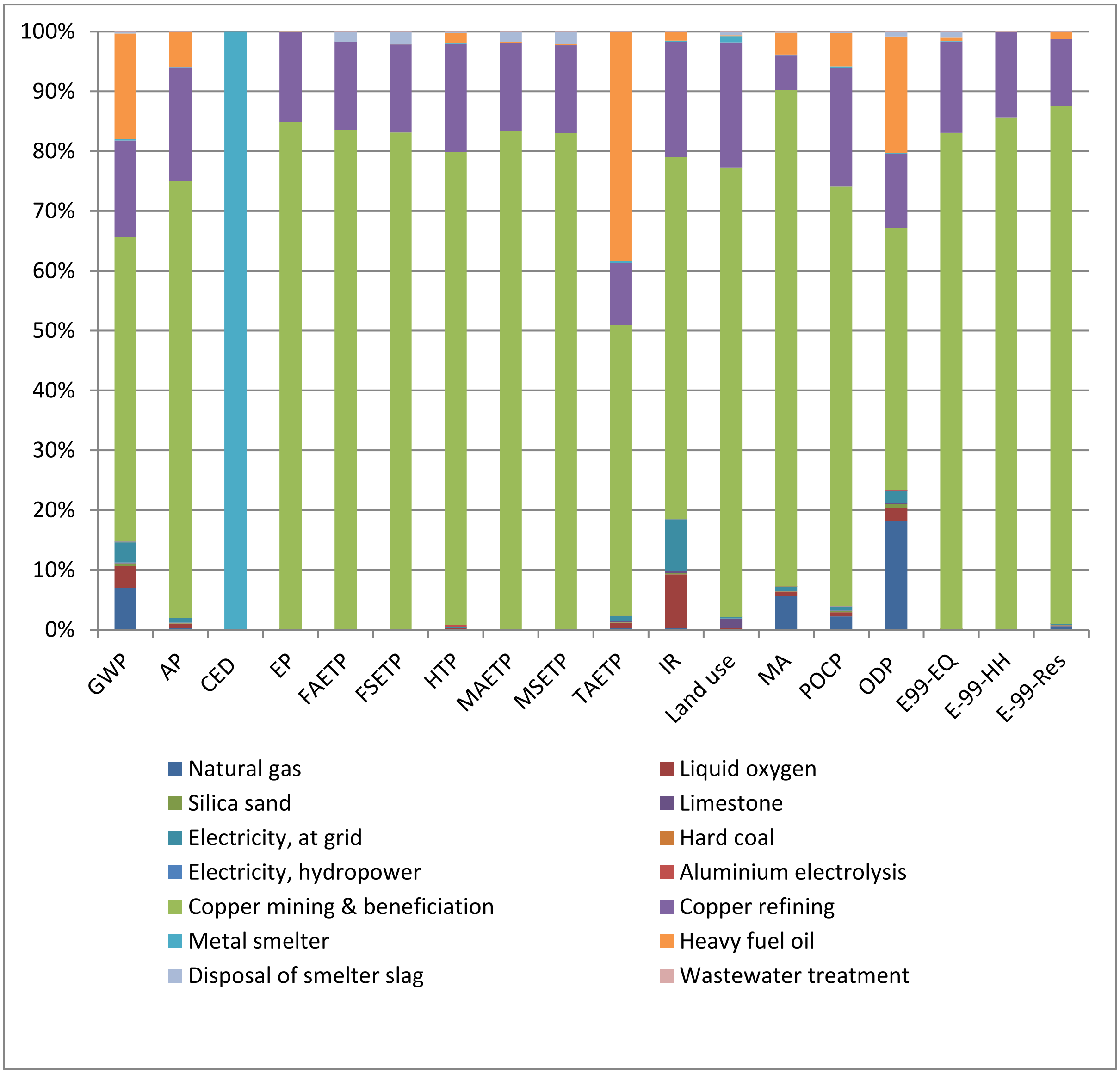

Figure 4.10: Environmental profile of 1 kg of primary copper cathode showing relative proportions of each impact categories due to contributing processes.

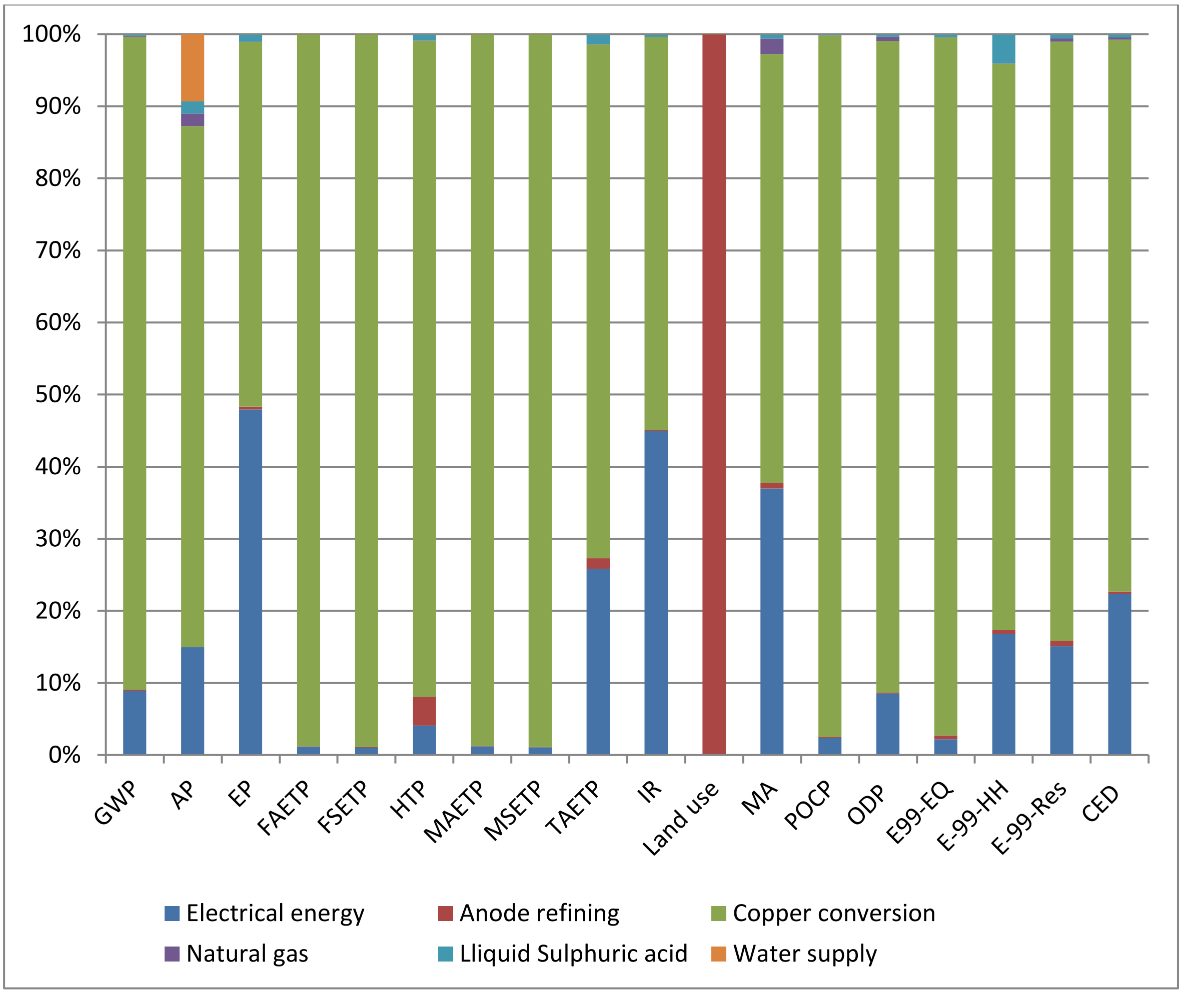

Figure 4.11: Environmental profile of 1 kg of secondary copper cathode showing relative proportions of each impact categories due to contributing processes.

4.3.1.5 Summary

In conclusion, primary copper performs worse in all impact indicators compared to secondary copper from recycled electronic and electric waste. It is highly material and energy intensive. The circular model of production is therefore more environmentally friendly. The environmental shows the main emissions hotspots for both methods of production and the processes that could benefit the most from interventions to reduce the emissions.

4.3.2 Lead

Lead is a dense metallic element found in ore with zinc, copper and silver. It is extracted mainly from galena. Lead is bluish-white in colour, soft and malleable. Lead has distinct chemical properties that allow many benefits to be derived from its use. It has very good density that is excellent for providing radiation protection and is highly used in hospitals, clinics, laboratories and nuclear plants. Lead is also malleable and resistant to corrosion making it very useful for roofing and cladding. Fig 1 shows lead consumption by product. 85.1 % of lead use is in the production of batteries.

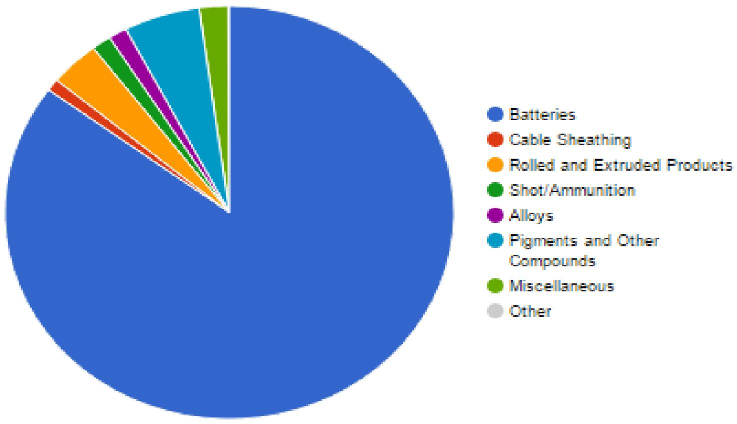

Figure 4.12: Lead Consumption by Product - Annual Amount (thousand tonnes) 2012 (Source: The International Lead Association ILA)

Lead batteries are used to power almost all types of vehicles including electric and hybrid vehicles and are the main storage options for renewable energy sources like wind turbines and solar cells. In the case of power failure or outages, lead batteries are often used as emergency back-up power in hospitals, by phone networks etc. (The International Lead Association, 2016). Due to its corrosion resistant properties, lead is also used to manufacture pipes for the movement of corrosive chemicals at chemical plants. Lead is therefore essential to modern day life.

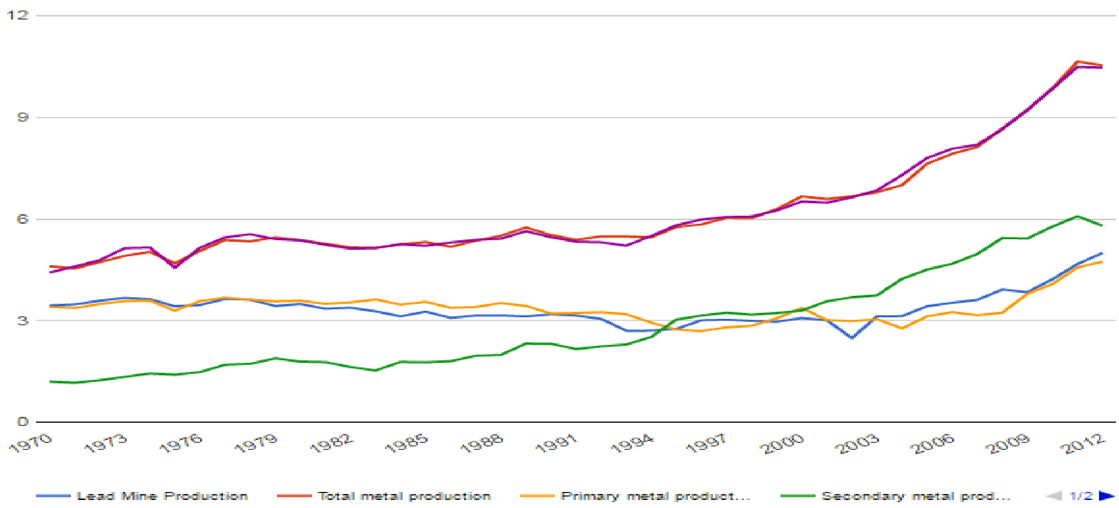

Figure 4.0.13: Global lead production and usage (million tonnes) 2012 (Source: The International Lead Association ILA)

Global lead production has been growing gradually, on an upward trajectory. Secondary lead production has also witnessed significant growth year after year from 3.688 million tonnes in 2002 to 5.799 million tonnes in 2012. Secondary lead production has steadily increased and now contributes more than half of total world lead production.

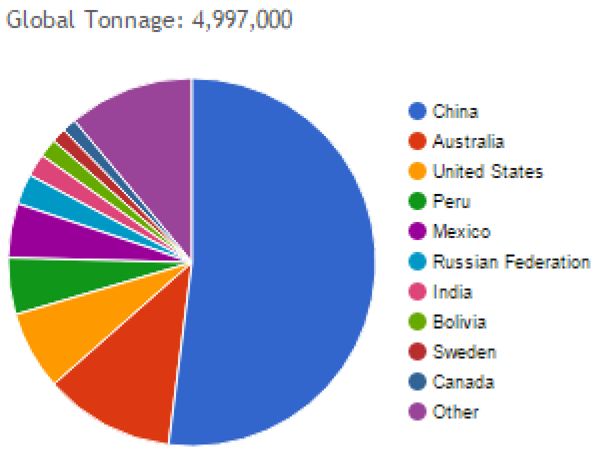

Figure 4.14: Lead Mine Production by country - Annual Amount (thousand tonnes) 2012(Source: The International Lead Association ILA)

China is the largest primary producer of lead, accounting for 52% of global output in 2012. Other key players in the industry are Australia 11.5%, United States 6.9%, Mexico, and Peru.

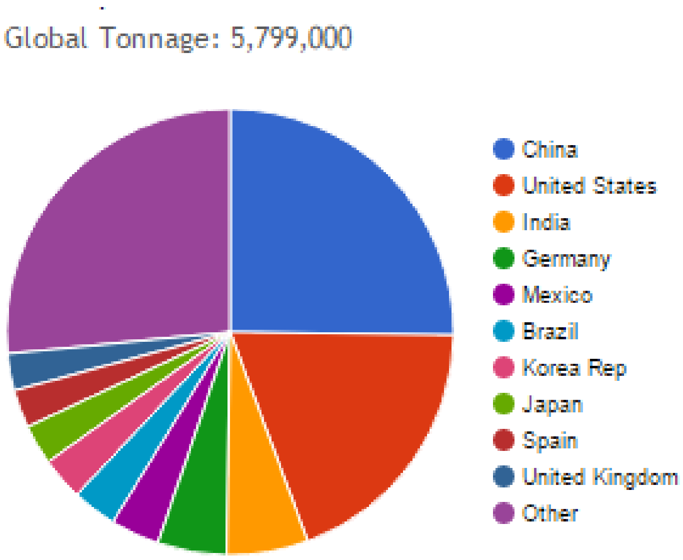

Figure 4.15: Lead recycling by country (secondary production) - Annual Amount (thousand tonnes) 2012 (Source: The International Lead Association ILA)

China is also the largest producer of secondary lead from recycling contributing 25.2% of recycled lead in 2012, followed by the United States with 19.1% and then India 5.9%. The UK produced 155,000 thousand tonnes amounting to 2.7%.

4.3.2.1 Lead Production: Primary supply chain

- **Mineral extraction:** this involves mining of the ore and separation of by-products. Galena is the most significant lead ore. Other main ores are cerrusite and angelsite (ILA, 2016). Lead ores usually occur together with zinc and at times also contain silver, copper and gold. The ore needs to be crushed into smaller pieces using several grinders and then separated. Waste rock (gangue) is also removed.
- **Processing:** froth floatation is the process used to separate the ores with high extraction efficiency. The end product is the lead concentrate that is about 50% lead.
- **Smelting:** this is the stage where lead ore is converted to lead metal. It can be a two-stage process or a single-stage process. The difference is in resource and energy efficiency. The one-stage process is more efficient. The first part of the smelting process is the roasting of the lead concentrate to remove remaining sulphur, converting the concentrate to lead oxide. Limestone, iron ore are commonly used as fluxing materials to reduce the amount of small lead particles blown out of the furnace. The second part involves the converting of the lead oxide to metal. This is done by putting the lead oxide is a furnace and heating to very high temperatures. The lead recovered at the end of this stage is referred to as lead bullion.

- **Refining:** this includes the removal of impurities from the lead such as copper, zinc, silver, gold etc. The main objective is to yield high purity lead. The refining process takes place in different stages. The bullion is heated and refined through a pyrometallurgical process such as the Parkes process to remove silver, and the Betterton-Kroll process, or through electrolytic refining which is more energy intensive but at the same time causes fewer emissions. The resulting lead is 99.9% pure.

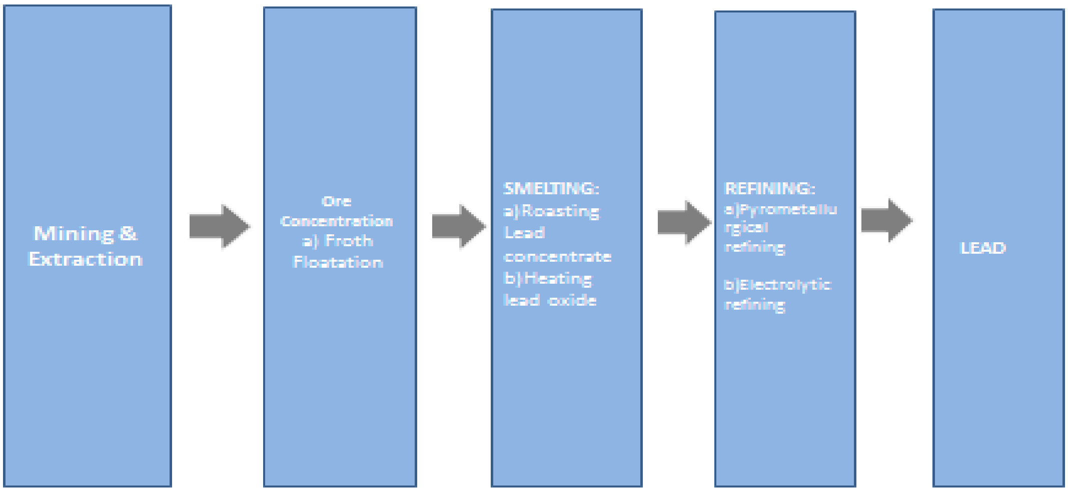

Figure 4.16: Primary lead supply chain

Secondary lead production involves the production of lead from scrap rather than ore. Lead scrap can be processed to produce refined metal. Sometimes with high quality scrap, it simply requires the re-melting of scrap, with limited extra processing. Sources of lead scrap include lead-acid batteries, sheet and cable sheathing, and lead pipes. Scrap collection has been encouraged by legislation. Directive 2006/66/EU on Batteries and Accumulators and Waste Batteries, mandates the recycling of batteries for member states, thereby preventing lead acid battery from being incinerated and ending up in landfill.

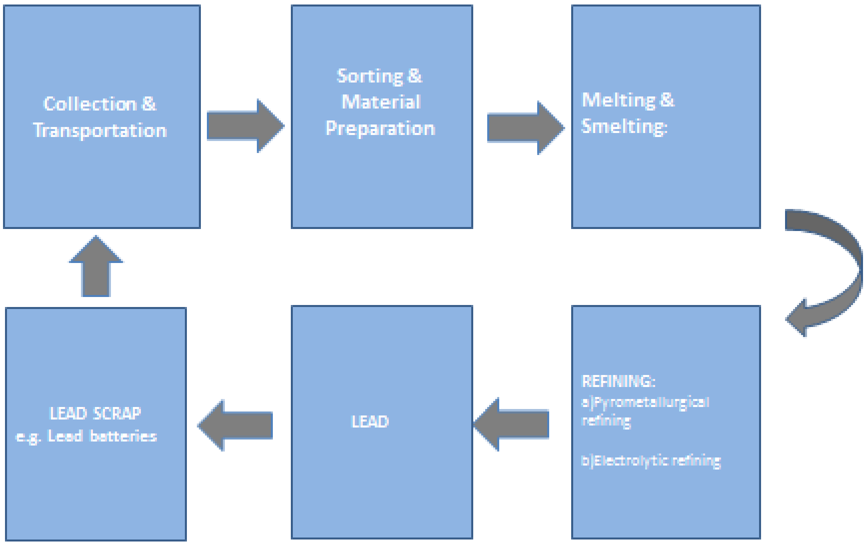

Figure 4.17: Secondary lead supply chain

The secondary supply chain starts with the collection of lead scrap. The scrap is collected and sorted. A large amount of scrap lead comes from used vehicle batteries. Lead can be recycled through pyrometallurgical routes. Lead recycling can be done repeatedly without any of its properties being degraded or deteriorated. Lead scrap then undergoes smelting in a rotary reverberatory furnace, producing lead metal and high lead content slag. The slag undergoes further slag treatment to produce lead with 75-85% purity, while the lead metal is refined.

4.3.2.2 Comparative analysis of linear vs circular economy model of lead production

The environmental impact of primary and secondary production of lead is examined using multiple life cycle impact assessment methods. The primary lead production begins with the mining and extraction as described above while the secondary production starts at with the collection, then sorting and remelting of the lead contained in lead acid batteries.

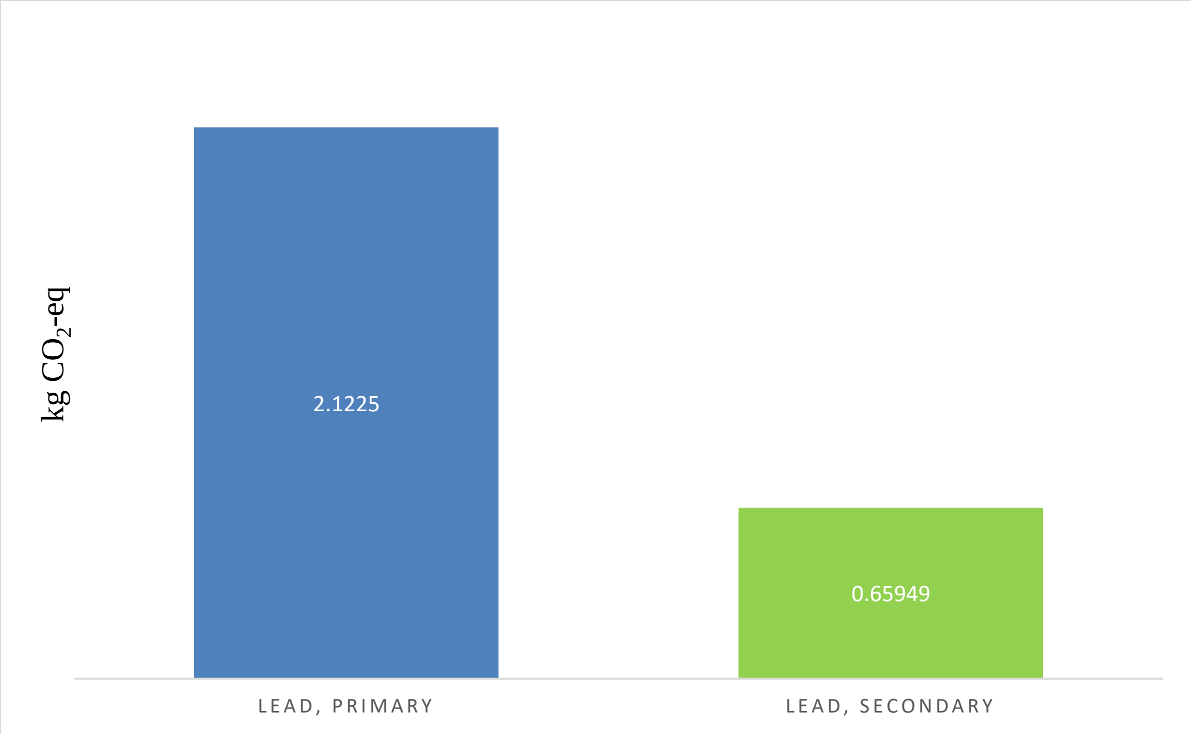

Figure 4.18: Comparative carbon emissions primary vs secondary lead production from batteries

The results compare the carbon emissions implications of producing lead using virgin lead ores through a linear production system to the production of lead using lead from recycled batteries as well as recycled electronic and electric scrap through a circular supply chain. Figure 4 19 illustrates this comparison. The result shows that the carbon emissions from the supply chain of primary lead are 2.12 kg CO_2-eq while that of recycled lead batteries is 0.65 kg CO_2-eq, falling further to 0.03 kgCO_2-eq when using recycled electronic and electric scrap. Primary lead is more carbon intensive than its secondary alternatives, highlighting that lead produced using recycling through a circular supply chain contributes significantly lower carbon emissions than that produced through mining virgin lead ores from mining through a linear production system.

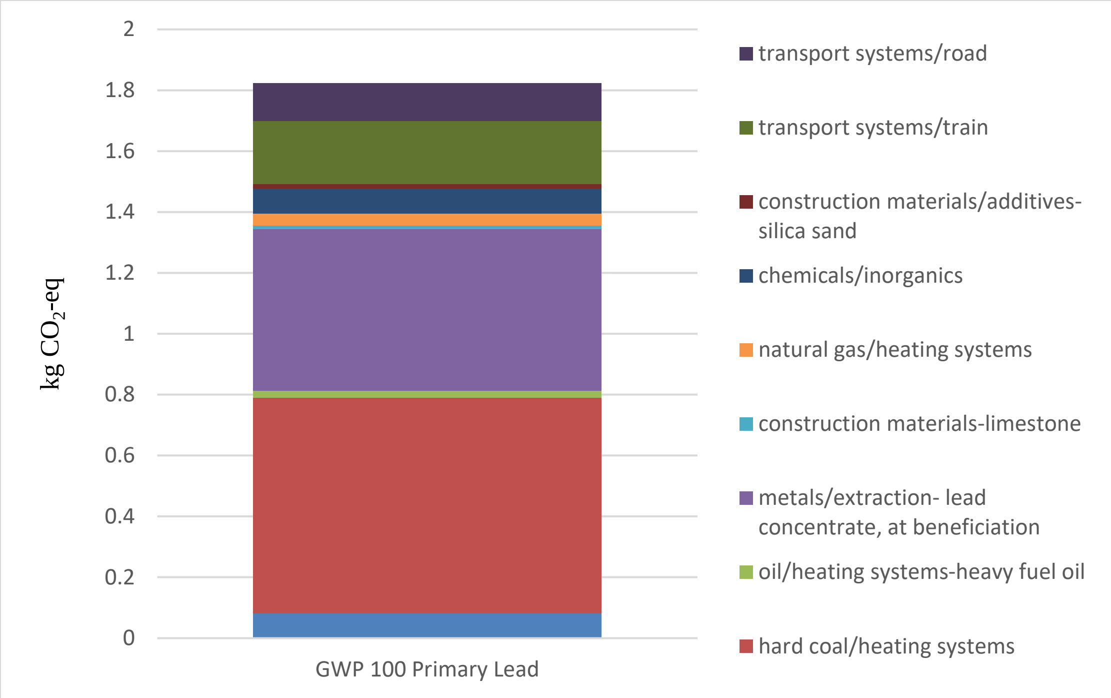

Figure 4.19: Breakdown of carbon emissions primary lead production

From Fig 4.20, it is observed that hard coal, burned in industrial furnace used for heating purposes is the main carbon hotspot of primary lead production. It contributes 39 % of total carbon emissions. Hard coal usages involve the combustion process and include softened water requirement, coal transport, ash disposal and electricity requirement. Lead beneficiation is also a significant carbon hotspot at 29%. Lead beneficiation consists of the mining and the beneficiation step with the mining infrastructure and disposal of overburden and tailings. This is followed by freight transport by rail with emissions of 0.2089 kgCO_2-eq, contributing 11 % of total carbon emissions. The rail transport consists of production, maintenance and disposal of vehicles'; 'construction and maintenance and disposal of railway tracks.

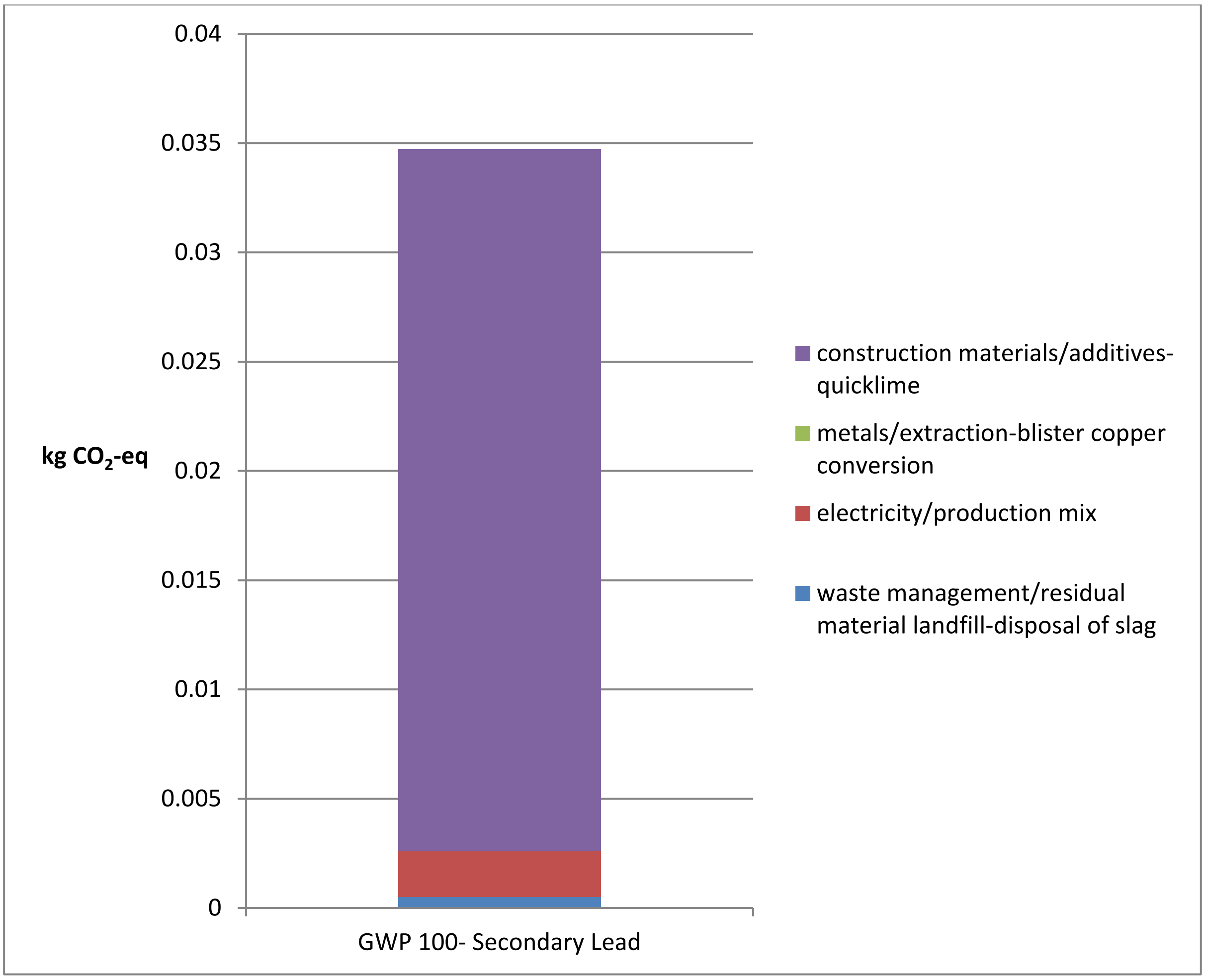

Figure 4.20: Breakdown of carbon emissions secondary lead production

Similarly, looking at the breakdown of emissions from secondary lead production from electronic and electric scrap, it is found that quicklime milled at plant is the main carbon hotspot contributing 92% of all emissions. Electricity is the second most significant hotspot accounting for 6% at 0.0021 kgCO_2-eq. waste management in the form of slag disposal makes up the remaining hotspots. This shows that it is the sourcing of raw material in this case scrap contributes little to total carbon emissions.

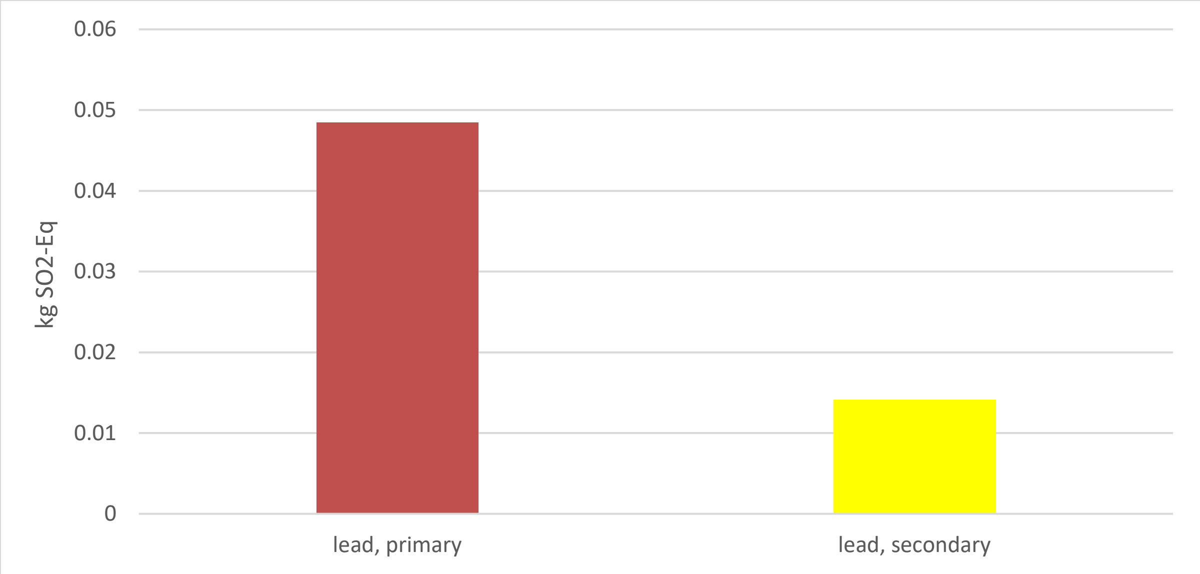

Figure 4. 21: Comparative acidification potential primary vs secondary lead production

Based on the acidification potential, it is observed again that secondary lead from recycling outperforms primary lead. Secondary lead is responsible for 0.000055 kg SO_2-Eq compared to 0.049 kg SO_2-Eq by primary production.

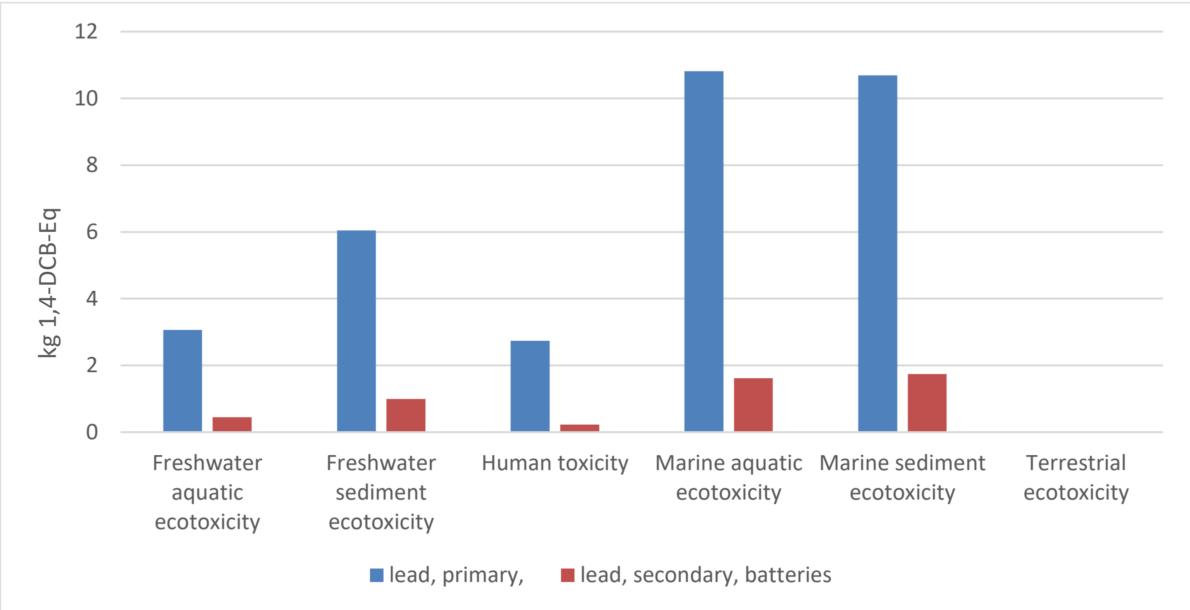

Figure 4.22: Comparative ecotoxicity indicators primary vs secondary lead production

Figure 4.23 presents the comparative analysis of lead mined from ore and lead recycled from electronic and electric scrap across six toxicological indicators based on the CML2001 method (Guinee, 2002). It can be seen that primary lead contributes more to all six indicators of ecotoxicity, especially marine aquatic and sediment ecotoxicity and is therefore less environmentally friendly than secondary lead.

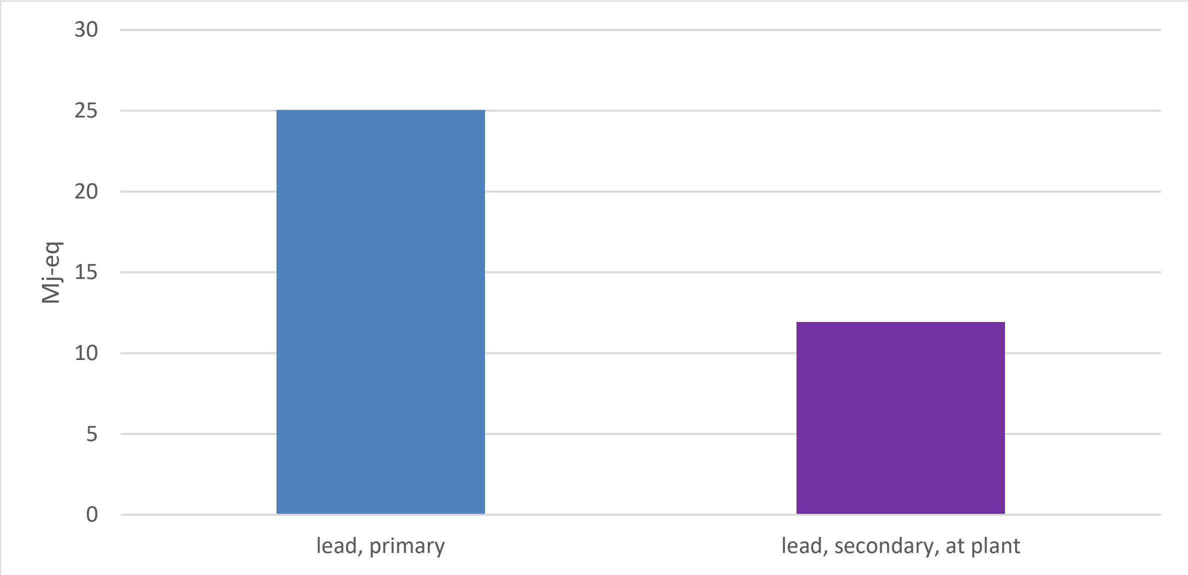

Figure 4.24: Comparative cumulative energy demand primary vs secondary lead production

Figure 4.24 compares cumulative energy demand between primary and secondary lead production. Secondary lead production used 0.2517 MJ-eq of energy to produce 1 kg of lead compared to 25.0581 MJ-eq of energy needed in primary lead to produce the same amount. In other words, secondary lead uses only 1% of cumulative energy required for primary lead production.

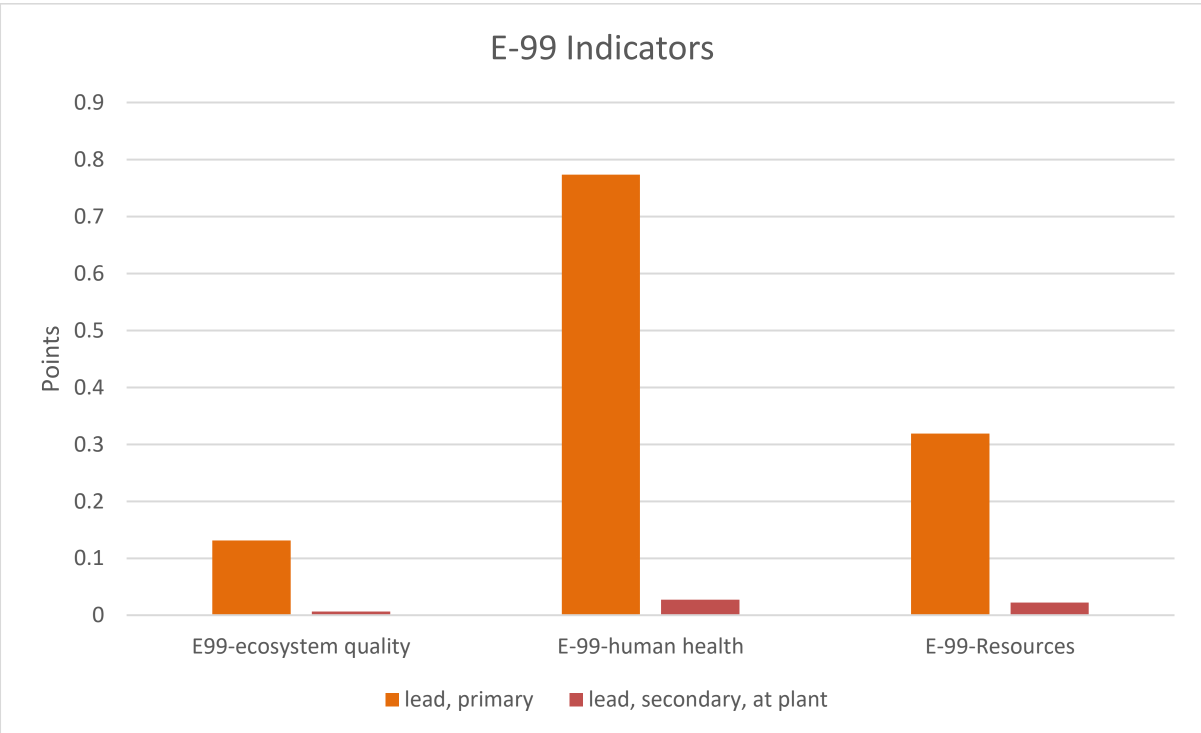

Figure 4.23: Eco-indicator 99 results for 1 kg of primary and secondary lead.

Examining the Eco-indicator 99 impacts, it can be seen that secondary lead also has significantly less impacts on the environment compared to primary lead, in terms of ecosystem quality, human health and resources.

4.3.2.3 Environmental profile of primary versus secondary lead

Figure 4.26 shows the environmental profiles of 1 kg of primary lead. All impact indicators have been normalised and the total of each impacts equal to a 100%. In Fig 10, Lead beneficiation is a significant contributor for eight indicators. It contributed eutrophication (79%), fresh water aquatic ecotoxicity (75%), fresh water sediment ecotoxicity (72%), human toxicity (50%), land use (75%), marine aquatic ecotoxicity (75%), marine sediment ecotoxicity (72%), malodours air (50%).Lead beneficiation lowest contributions were to ionising radiation (11%), acidification (23%), and stratospheric ozone depletion (28%), GWP100 (29%), terrestrial ecotoxicity (32%), and photochemical oxidation and land use (34%). Furthermore, hard coal, burned in industrial furnace used for heating purposes is also a main emissions contributor in the lead production of primary after lead beneficiation. It contributed photochemical oxidation (41%), GWP100 (39%), terrestrial ecotoxicity (24%), human toxicity (20%), and land use (19%).

Hard coal usages involve the combustion process and include softened water requirement, coal transport, ash disposal and electricity requirement. Disposal of slag to landfill contributes 55% of acidification potential, while rail transport contributes the most to ionising radiation at 33%. Similarly, considering cumulative energy demand, it can be seen that transport, hard coal and lead beneficiation contribute about a quarter each at 24%, 28% and 25% respectively. Largely electricity and chemicals make up the remainder. In terms of Eco-indicator 99 impacts, Lead beneficiation is the highest contributor to ecosystem quality (97%), and resources (97%), while disposal of slag to landfill contributes the most to human health at 72%.

These impacts from lead pertain to the fact that during its extraction, it can penetrate water bodies through a number of facilities including runoff, sewage and industrial waste streams. High levels of lead in waterbodies can damage reproductive systems of certain aquatic life. By extension, it can lead to blood changes and neurological malfunction in fish and other aquatic animals. Based on human toxicity, the accumulation of lead can accumulate in certain body organs rendering them damaged. The impact of lead due to malodours air is large due to the fact lead is released into the air during production and can cause soil and water contamination (Ibn-Mohammed et al., 2016).

Figure 4.27 shows the environmental profiles of 1 kg of secondary lead. From Fig 11, waste management i.e. disposal of slag is the most significant contributor for six indicators in secondary copper production. It contributed fresh water aquatic ecotoxicity (99%), fresh water sediment ecotoxicity (99%), marine aquatic ecotoxicity (99%), marine sediment ecotoxicity (99%), land use (84%), and acidification (59%). The lowest contribution of waste management was to GWP100 (1%), and then ionising radiation (2%), and photochemical oxidation (2%). Disposal of slag comprises of short-term emissions to water from leachate as well as long-term emissions from landfill to ground water.

In addition, the second most significant contributor to inventory impacts is construction materials and additives. It contributed GWP100 (92%), eutrophication (51%), Photochemical oxidation (97%), stratospheric ozone depletion (87%), and terrestrial ecotoxicity (55%). Electricity is also a key contributor, responsible for acidification (58%), ionising radiation (50%), malodours air (38%), and terrestrial ecotoxicity (37%). Metal extraction is the least contributor to the impact indicators.

From the Eco-indicator 99 impacts perspective, Electricity contributes (87%) of ecosystem quality, construction materials and additives contribute (80%) & (81%) to human health and resources respectively. Lastly, examining the cumulative energy demand impact, it is found that (75%) of consumption goes to construction materials and additives with electricity making up (18%), and finally waste management i.e. disposal of slag contributing the remaining 7%.

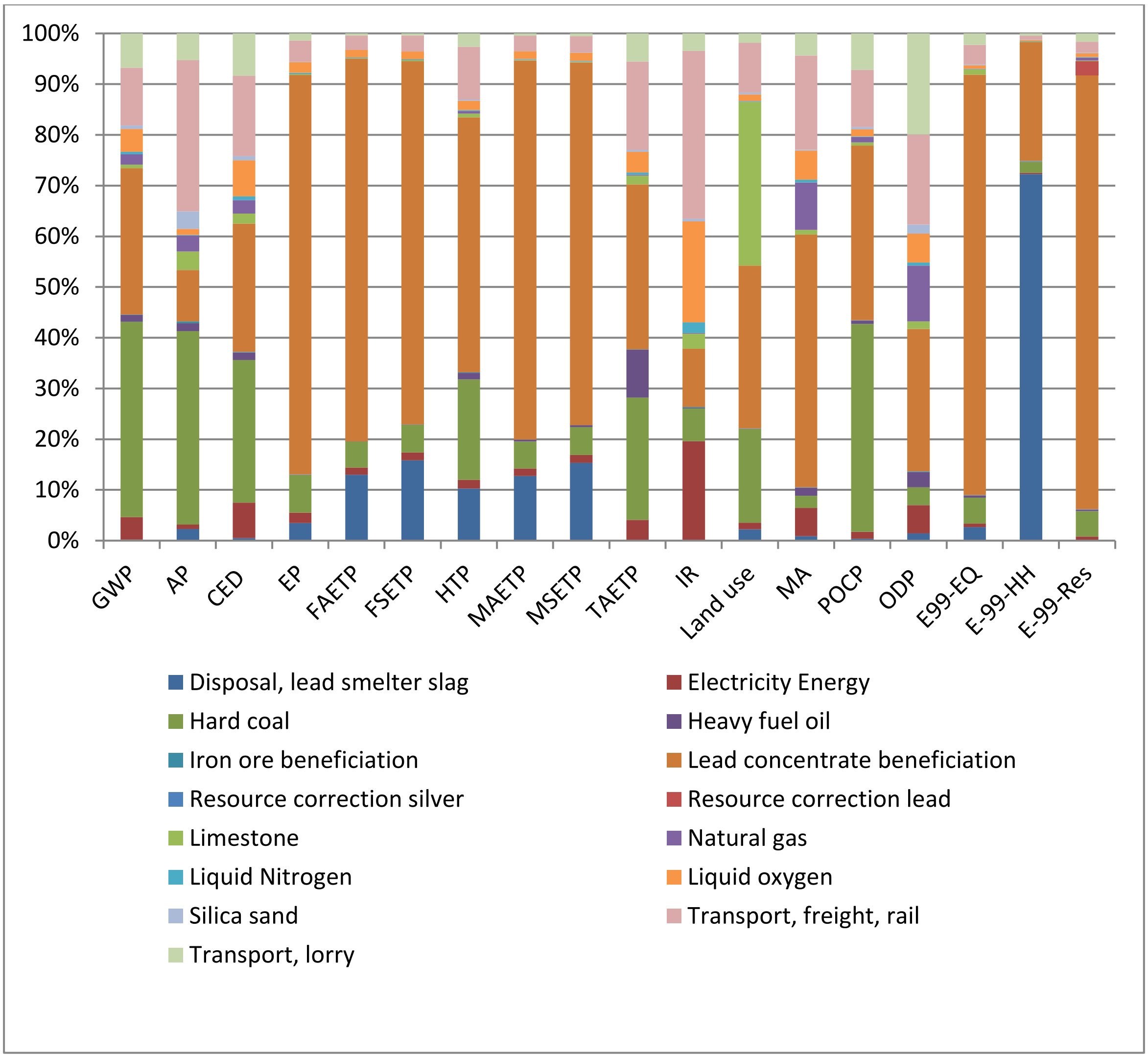

Figure 4.24: Environmental profile of 1 kg of primary lead production showing relative proportions of each impact categories due to contributing processes.

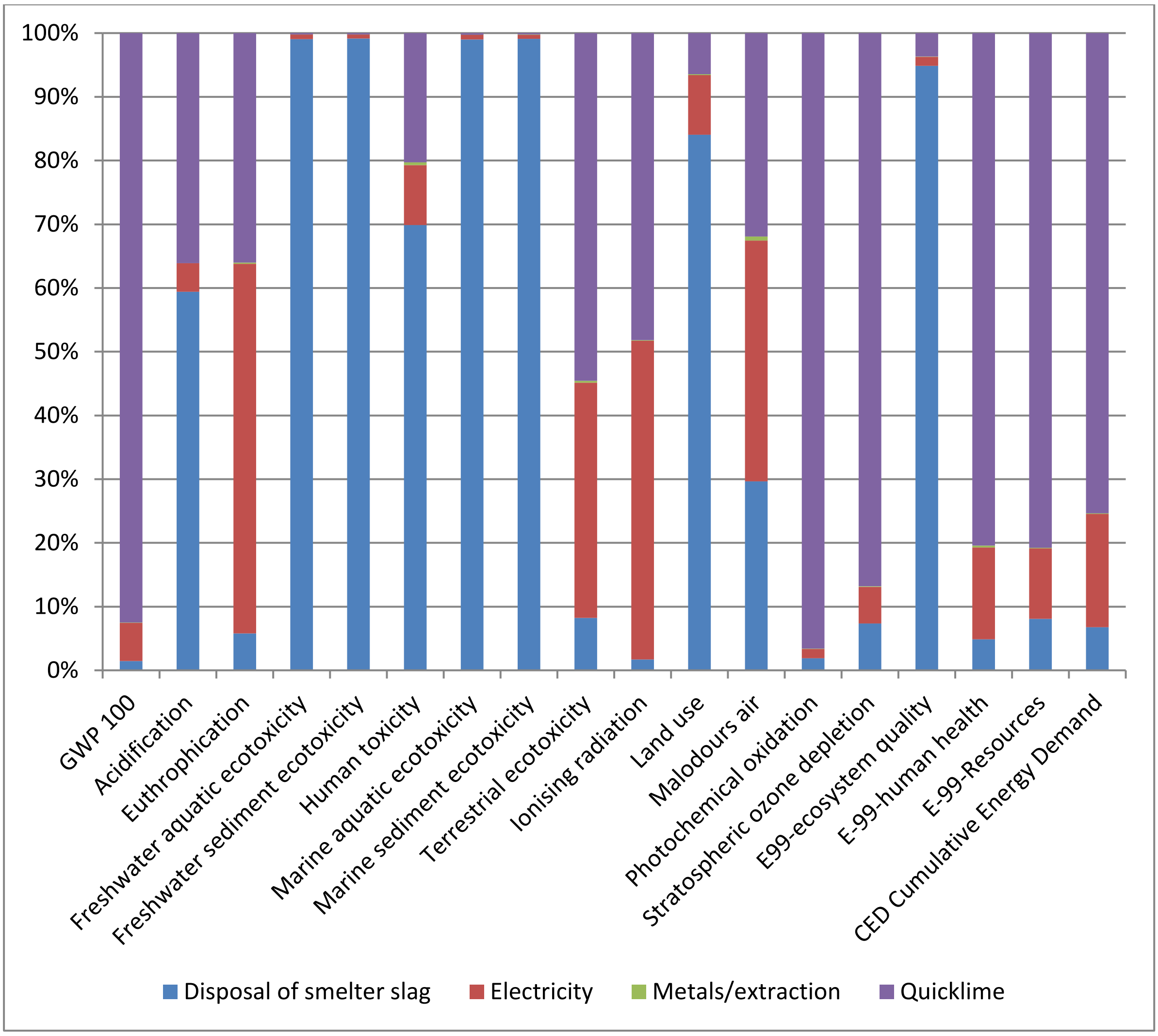

Figure 4.25: Environmental profile of 1 kg of secondary lead production showing relative proportions of each impact categories due to contributing processes.

4.3.2.4 *Allocation issues- the case of lead and bismuth*

When discussing transitions towards a circular economy with respect to the metal sector where mining of such metals is an important issue, there is a tendency to feel that minerals and minerals ores which are aggregates of different metals and chemicals when extracted and refined together should minimize costs and impacts. However, the issue is not as straightforward as it seems. In LCA modelling, such issues are analysed based on allocation principles especially in instances where emissions intensity data of a given metal or product are not available in well-established LCA database like Ecoinvent or SimaPro. In the context of the current work, the environmental lifecycle impact (LCI) data of all the metals namely copper, lead, nickel and lead considered are available in the Ecoinvent database. As such, the need to employ allocation principles based on criteria such as economic, mass, physical or energy was not considered. Given that Ecoinvent database is a globally recognised inventory, all environmental information derived from it are regarded as satisfactory source of emissions intensity data.

The use of allocation based on the aforementioned criteria becomes useful when there is lack of emissions intensity data for a particular material within the Ecoinvent database. By studying the relationship between two or more materials that are extracted together, allocation procedures can then be used accordingly, although there are plenty of research issues pertaining to the use of allocation principles in life cycle assessment economic allocation (Guinée et al., 2004; Ardente and Cellura, 2012). For the purpose of the current work, it will be counterintuitive to employ the use of allocation when data at a determined level of detail is available for the individual metals within the Ecoinvent database. Although copper and nickel and in some instances lead can be mined together, but the individual datasets for each of the metals are available within the Ecoinvent database and issues pertaining to allocation has already been taken into consideration.

Moreover, from a circular economy perspective, the fact that aggregates of different metals and chemicals are extracted and refined together does not necessarily lead to minimisation of costs and impacts. Consider the case of bismuth, for example. Emissions intensity data of bismuth is not available in Ecoinvent. Bismuth is primarily obtained as a by-product of smelting of copper and lead and sometimes from tin, tungsten and zinc ores from China (Naumov, 2007; Nuss and Eckelman; 2014; Ku et al., 2003). In fact, roughly 90-95% of bismuth available in the market is derived as a by-product of lead smelting (Liu et al., 2013). When bismuth is retrieved as a co-product during the smelting of lead, the quantity yielded is a small fraction by mass, yet bismuth is a moderately priced metal, costing more than lead and zinc, but less than gold or silver (Ku et al., 2003). As such, allocation on the basis of economic value has been adopted to evaluate its environmental profile given that it provides a more reflection of the causality of the production and recovery process.

From an environmental perspective, the carbon footprint (GWP) of bismuth oxide surpasses that of lead due to additional processing and refining steps which pose extra challenges in metallurgical recovery, even though it is retrieved as a by-product of lead. However, lead is very toxic but bismuth is not. Bismuth is neither bioaccumulative nor carcinogenic (as compared to lead whose GWP is low but it is bioaccumulative and carcinogenic) and that is why it finds application in medicinal practices especially for treating gastric conditions (Ku et al., 2003). As such, looking at this from a circular economy perspective, the issue becomes even more difficult to analyse when it comes to policy decision making. This is one of those dilemmas that the issue of environmental and economic considerations poses when discussing resource efficiency and circular economy concepts. One material (bismuth) is a by-product of another material (lead). Lead is toxic but finds applications in a number of areas and its elimination in a number of products has been at the forefront of environmental policy research. Bismuth has a higher carbon footprint, not toxic and has medicinal value. This scenario therefore poses more questions and debate when it comes to environmental decision making and stewardship as we transit from linear to circular economy.

4.3.3 Nickel

Nickel is well known for its use in the making of coins used a currency for trade and exchange. Nickel displays a combination of ferrous and nonferrous metal properties, as such is referred to as a transition metal. Nickel is siderophile as well as chalcophile i.e. associates with both iron and sulphur (USGS Mineral information, 2016). Pentlandite, the most common nickel sulphide mineral accounts for the majority of nickel produced in the world. Nickel has a high melting point, possesses good ductility and is highly corrosion and oxidation resistant. These characteristics combined are what give it its versatility and make it highly valuable. Nickel is most commonly used in the manufacture of stainless steel and nickel alloys offering corrosion and temperature resistance. These alloys are used in the aero industry for turbines and jets, coins, welding rods, magnets, ship building, electronics, and surgical implants. Nickel compounds are used for electroplating. Figure 4.26 shows the growing global Nickel demand is on an upward trajectory.

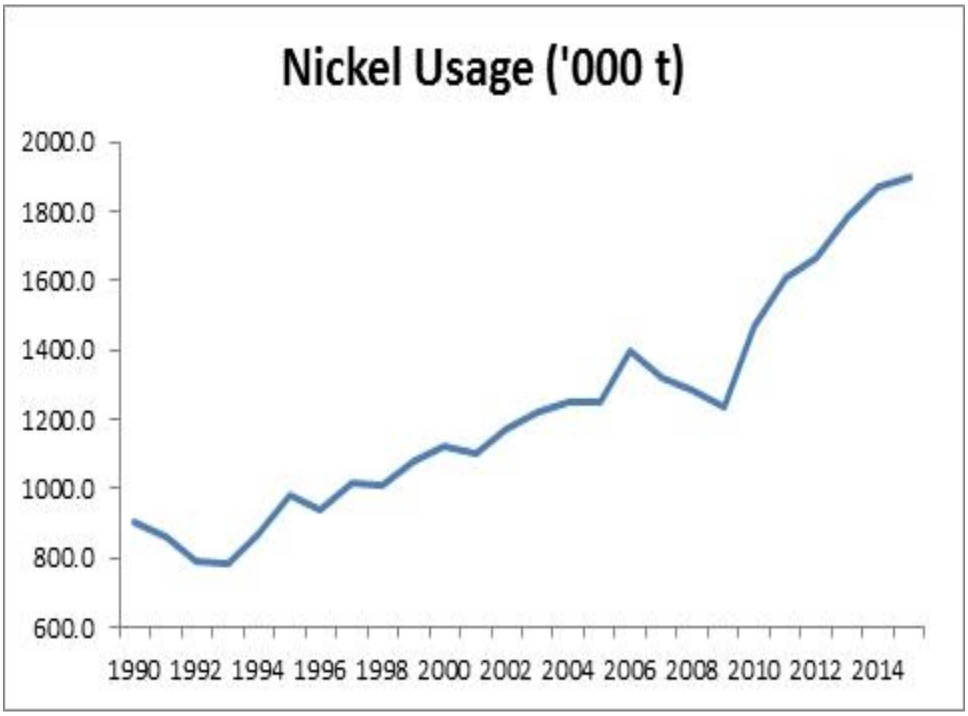

Figure 4.26: World Nickel production (Source: International Nickel Study Group INSG, 2016)

Stainless steel is the key driver of nickel demand. Nickel improves durability and corrosion resistance of steel. The three top uses of nickel in stainless steel are food processing equipment, catering and chemical process equipment.

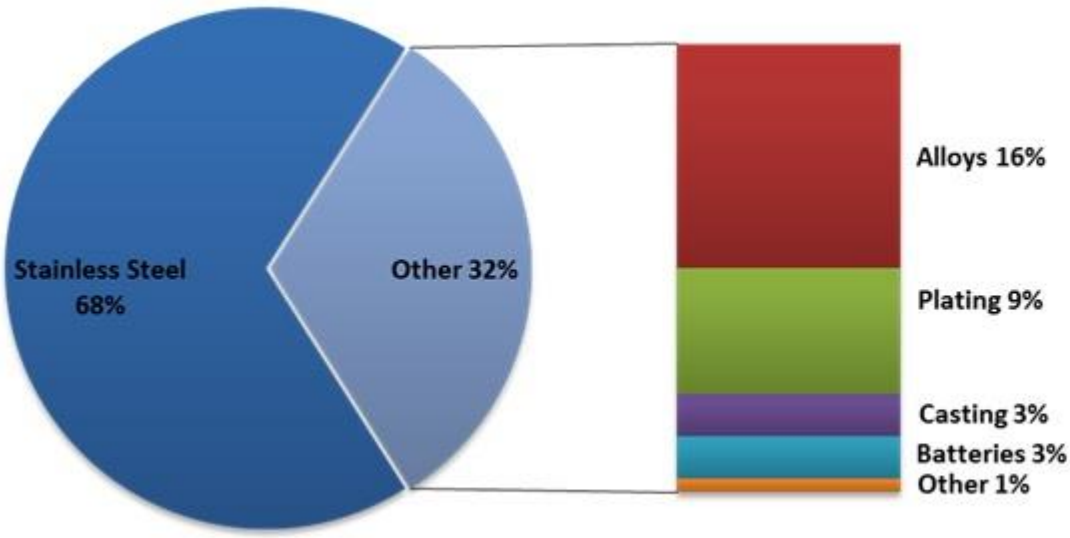

Figure 4.27: Nickel use by end product (Source: International Nickel Study Group INSG, 2016)

4.3.3.1 Primary (linear) production of nickel

Primary nickel production involves the mining of ores. Nickel is found in two ore types that are very different from one another, namely sulphide and laterite ores. Primary production is in three stages; Find – mine – process. The mining process starts with very deep hole dug in the earth's crust to form a tunnel to reach the nickel ore. The tunnel serves a route to safely get miners, equipment and vehicles to the ore. The ore is broken down usually through the use of explosives to make it smaller and easier to transport. The smaller ore is scooped and transported mainly using large haulage vehicles to the surface. From then on, the ore is taken to refining mills using trucks. The ores are then crushed, using different crushers such as jaw crushers and cone crusher to reduce them to an even smaller marble-size. The marble sized ore is further crushed in large ball mills with a mixture of water to form a kind of slurry. The slurry is then refined further in several floatation tanks using various chemicals and chemical processes to separate the nickel and remove impurities. Nickel is very commonly mined with copper and as such copper is usually a by-product. The nickel concentrate is then smelted and refined further until it yields pure 99.9% nickel. The nickel then goes off to various industries and companies to be made into various useful products.

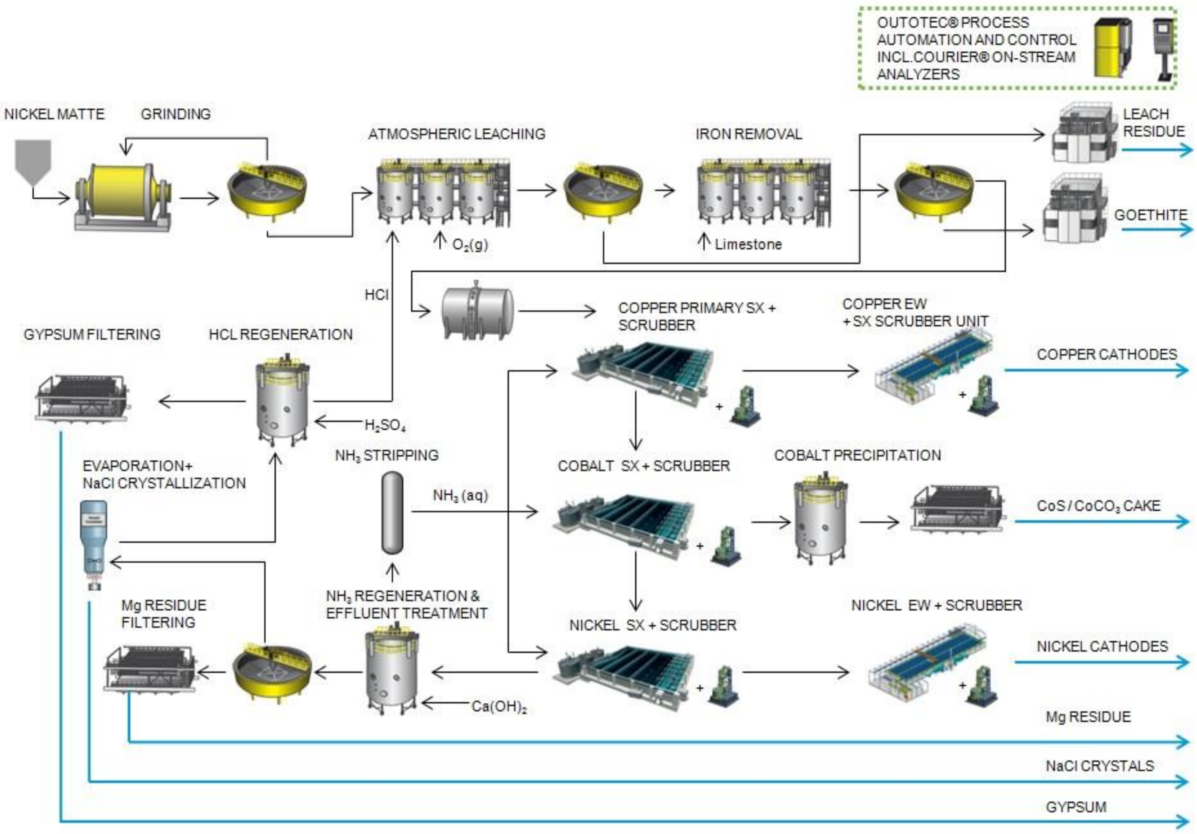

Figure 4.30: Primary nickel production stages source: (Outotec, 2017)

4.3.3.2 Secondary (circular) production of nickel from electronic and electric scrap

A large amount of nickel scrap is recovered from the stainless steel scrap, coming from old consumer and household products. Scrap is also available from electric and electronic waste such as batteries, aircraft parts, old and outdated, salvaged factory machinery and equipment. Industrial scrap such as turnings, casting wastes and solids from alloy products manufacturing are also sources of secondary nickel. The secondary production considered here is much like the secondary production of copper.

Table 4.1: Nickel-containing intermediate products and average nickel contents, Europe 2000

Product	**Ni-concentration (in %)**
Electrical and Electronic Equipment	
Computers	0.8503
Televisions	0.12
Telephones	0.3
Stereos/radios	0.3
Food grinders, mixers, etc.	0.9

Secondary nickel production starts with nickel scrap. It therefore avoids the energy and resource intensive stage of mining that occurs in the linear primary production of nickel discussed above. The scrap is collected, inspected, sorted and graded. The scrap can be classified into high and low grade scrap. The scrap enters the production process depending on their nickel content at either the smelting stage or fire refining stage. Pure nickel scrap goes straight to moulding and casting and does not go through the cathode production stages. Slags rich in nickel such as refining slags are also used as raw materials in secondary nickel production and are usually recirculated at previous production stages, particularly the converting, or the smelting stage. The refining of scrap nickel involves melting in an electric arc or reverberatory furnace, usually with lime and an alloying agent. Further refining is done to the product to produce a high purity nickel material.

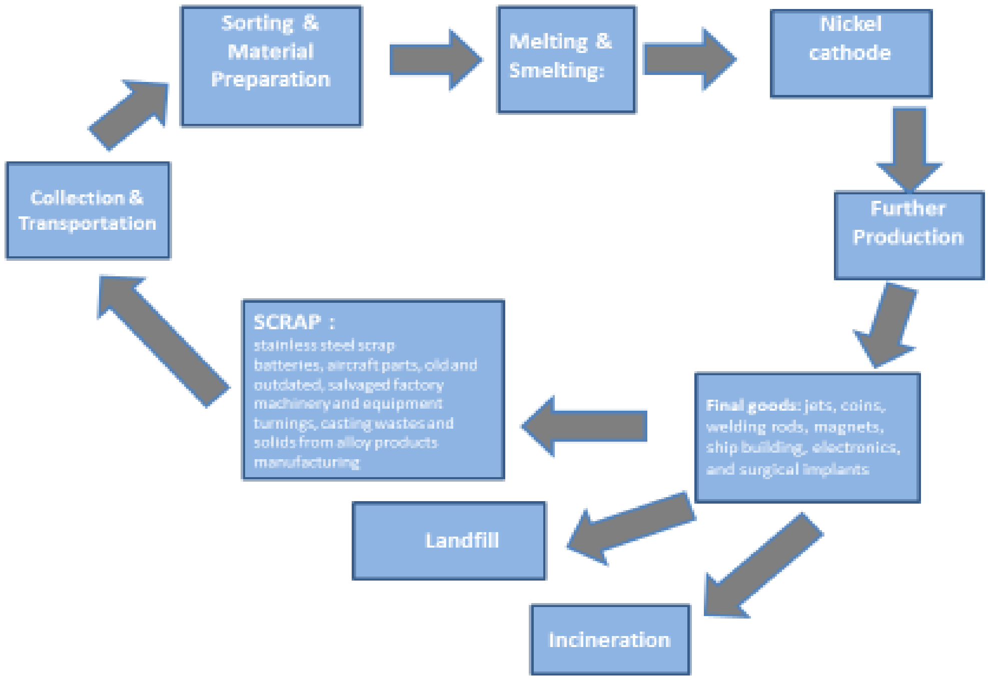

Figure 4.28: Secondary nickel production supply chain

4.3.3.3 Comparative analysis of linear vs circular economy model of nickel production

Using 3 life cycle impact assessment methods namely: Impact-oriented characterisation (CML 2001), Cumulative Energy Demand (CED), Eco-indicator 99 (Egalitarian perspective), the environmental impacts of primary and secondary production of Nickel are analysed in this section. The first analysis compares the carbon emissions implications of producing nickel cathodes using virgin nickel ores through a linear production system to the production of nickel cathodes using Nickel recycled scrap from electric and electronic scrap through a circular supply chain. The comparison is shown in Figure 4.30.

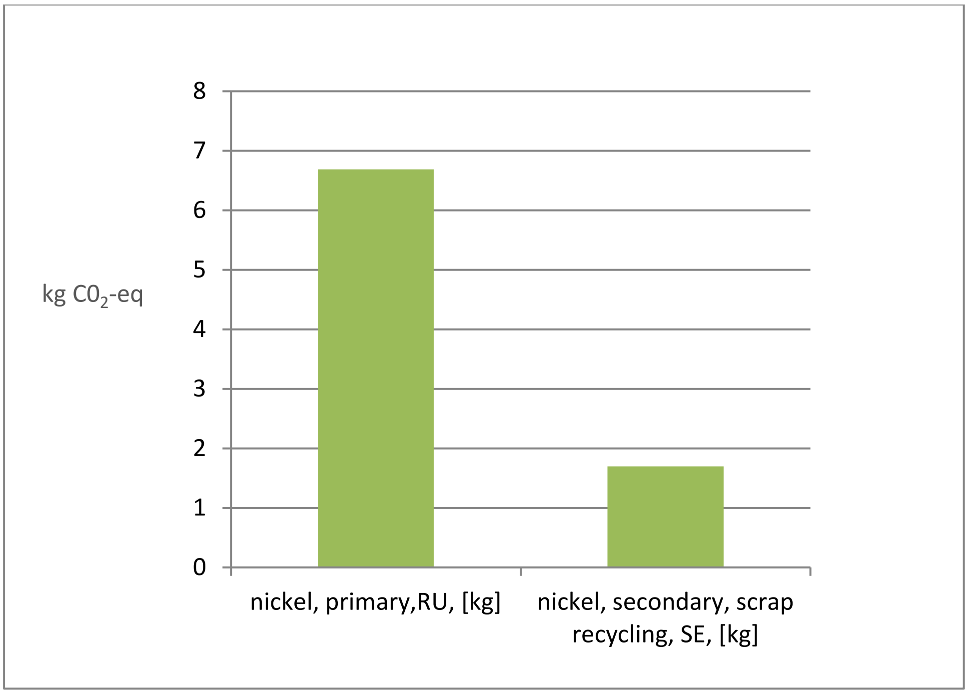

Figure 4.29: Comparative carbon emissions primary vs secondary nickel production

The result shows that the carbon emission from the supply chain of primary Nickel is 6.484 kg CO_2-eq while that of circular nickel from electric and electronic scrap is 1.697 kg CO_2-eq. Primary Nickel is approximately 4 times more carbon intensive than its secondary alternative, indicating that Nickel produced using recycling through a circular supply chain contributes significantly lower carbon emissions than its counterpart produced from mining nickel through a linear production system.

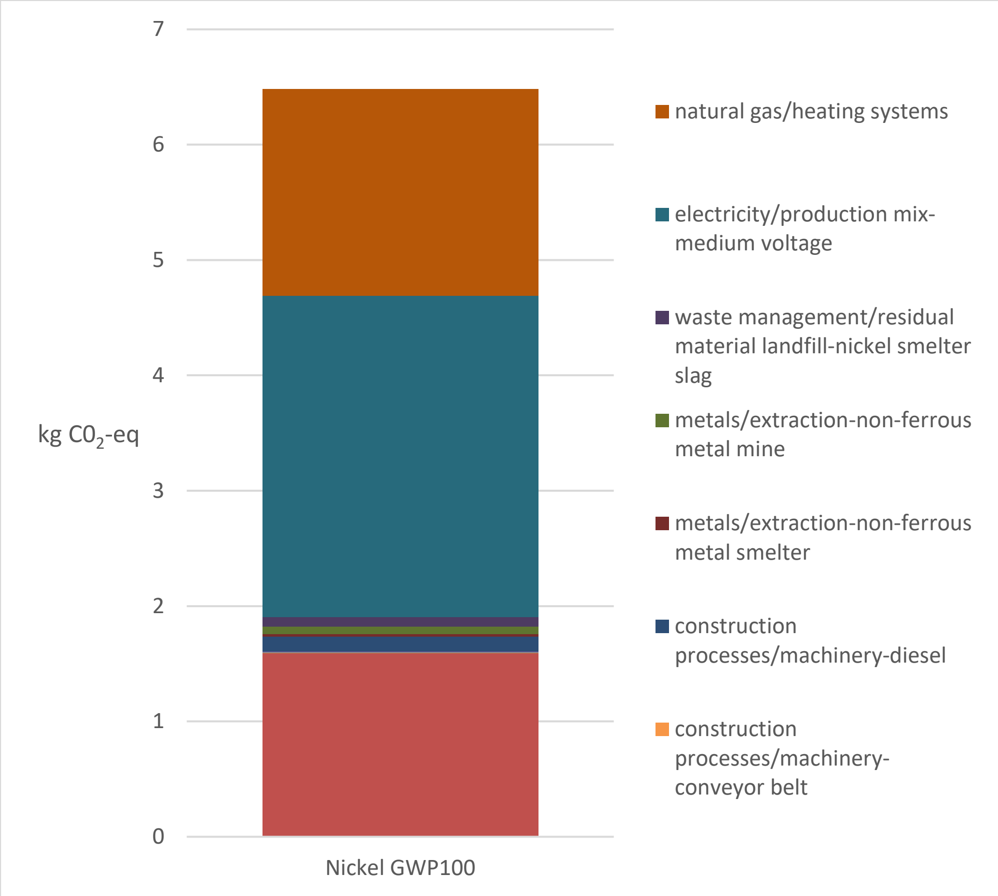

Figure 4.30: Breakdown of carbon emissions primary nickel production

Figure 4.33 shows that electricity use is the main carbon hotspot of primary Nickel production, contributing 43 % of total carbon emissions. Hard coal usages involve the combustion process and include softened water requirement, coal transport, ash disposal and electricity requirement. Natural gas is also a significant carbon hotspot at 28%. Natural gas is used for heating and combustion in the industrial furnace during the roasting, smelting and refining phase. The next highest carbon emissions contributor is the inorganic chemicals with emissions of 1.591 kg CO_2-eq, contributing 25 % of total carbon emissions. All the rest contribute not more than 2% each respectively.

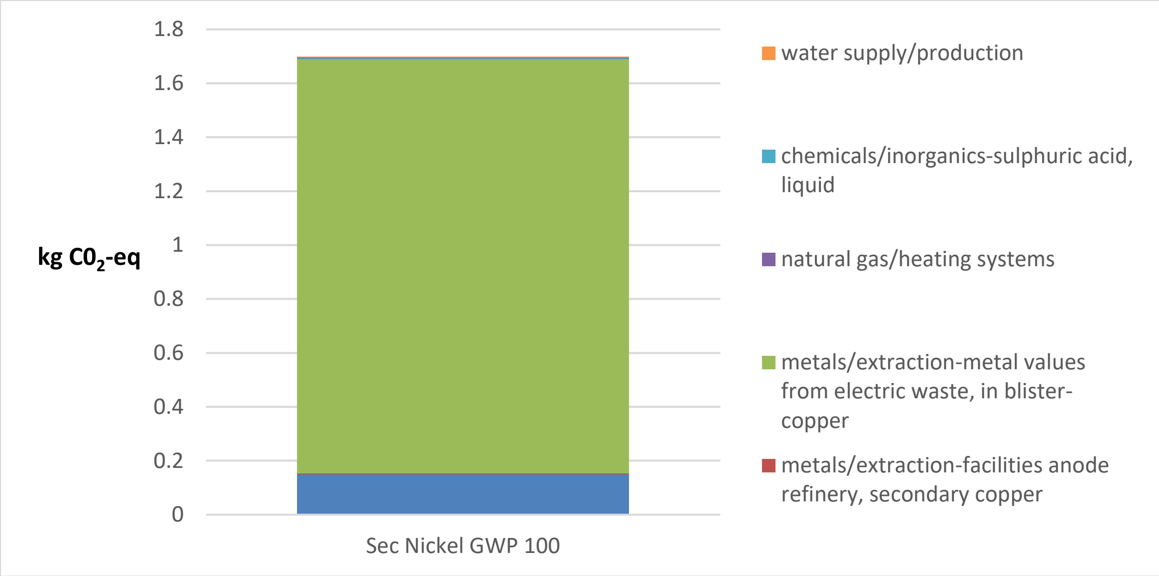

Figure 4.31: Breakdown of carbon emissions secondary nickel production

Likewise, looking at the breakdown of emissions from secondary nickel production from electronic and electric scrap, it is found that multi-stage electric waste extraction is the main carbon hotspot contributing a whopping 91% of all emissions. This involves the conversion of Copper in a Kaldo Converter and treatment in converter aisle. The secondary scrap is refined in Boliden smelters. Leaching and high temperature reactions help to separate out the various metals. Electricity is the second most significant hotspot accounting for 9% at 0.1508 kg CO_2-eq. All other processes contribute less than a percent. Secondary nickel production is almost identical to secondary copper production. This is because Nickel is very commonly mined with copper and as such copper is usually a by-product.

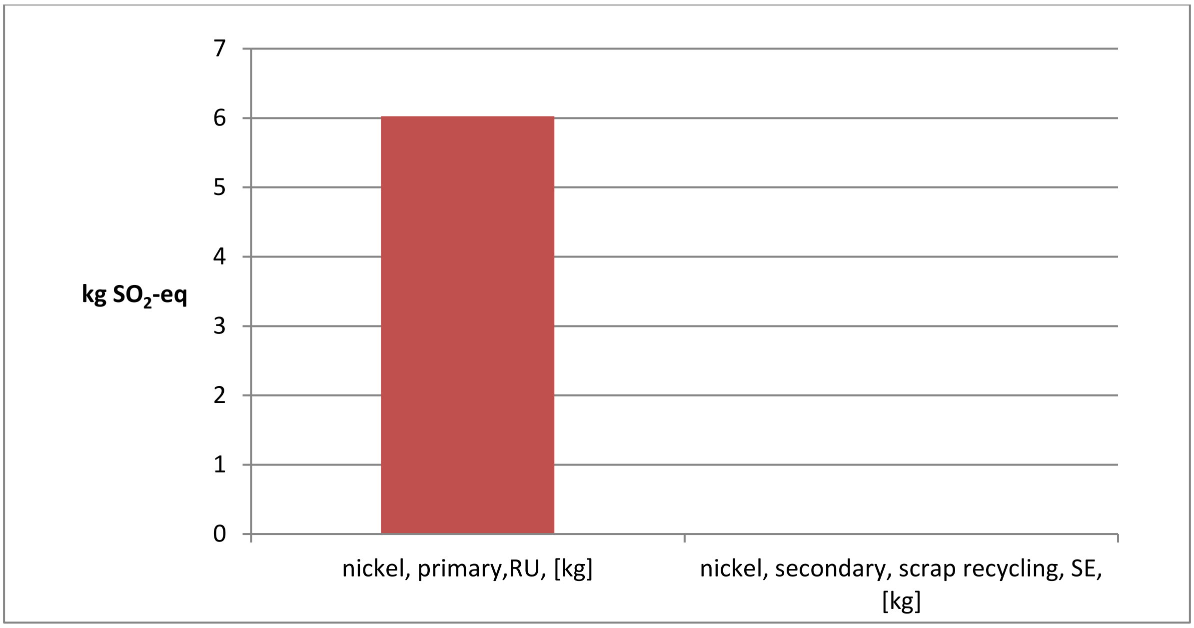

Figure 4.32: Acidification potential of 1 kg primary vs secondary nickel production

Furthermore, looking at another impact indicator, acidification potential, we see that again secondary lead from recycling outperforms primary lead. Secondary Nickel from electric and electronic scrap is responsible for 0.0036 kg SO_2-Eq compared to 6.0241 kg SO_2-Eq by primary. This means that primary nickel acidification potential is magnitudes higher than the acidification potential of secondary electric scrap nickel.

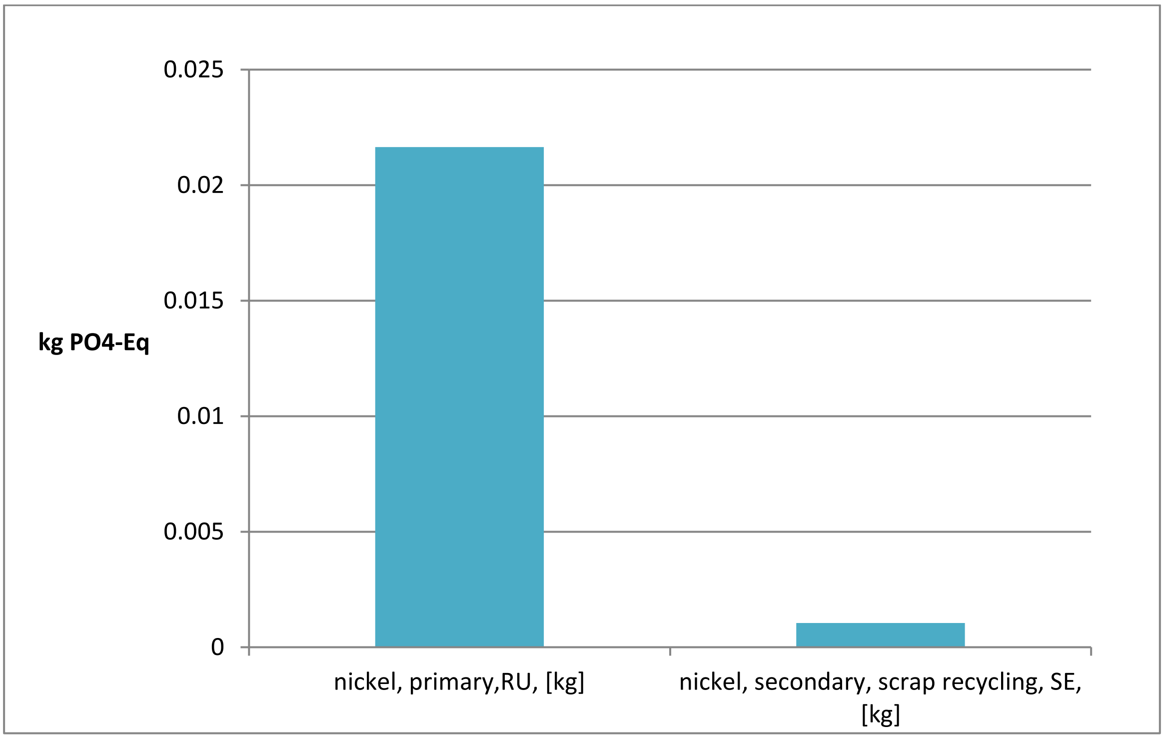

Figure 4.33: Eutrophication potential of 1 kg primary vs secondary nickel production

The breakdown of eutrophication potential for both primary and secondary nickel is presented in Fig. 4.36. It can be observed from the graph that primary nickel (0.0217 kg PO_4-Eq) contributes significantly more than secondary nickel from electric and electronic scrap (0.0010 kg PO_4-Eq) in terms of eutrophication potential.

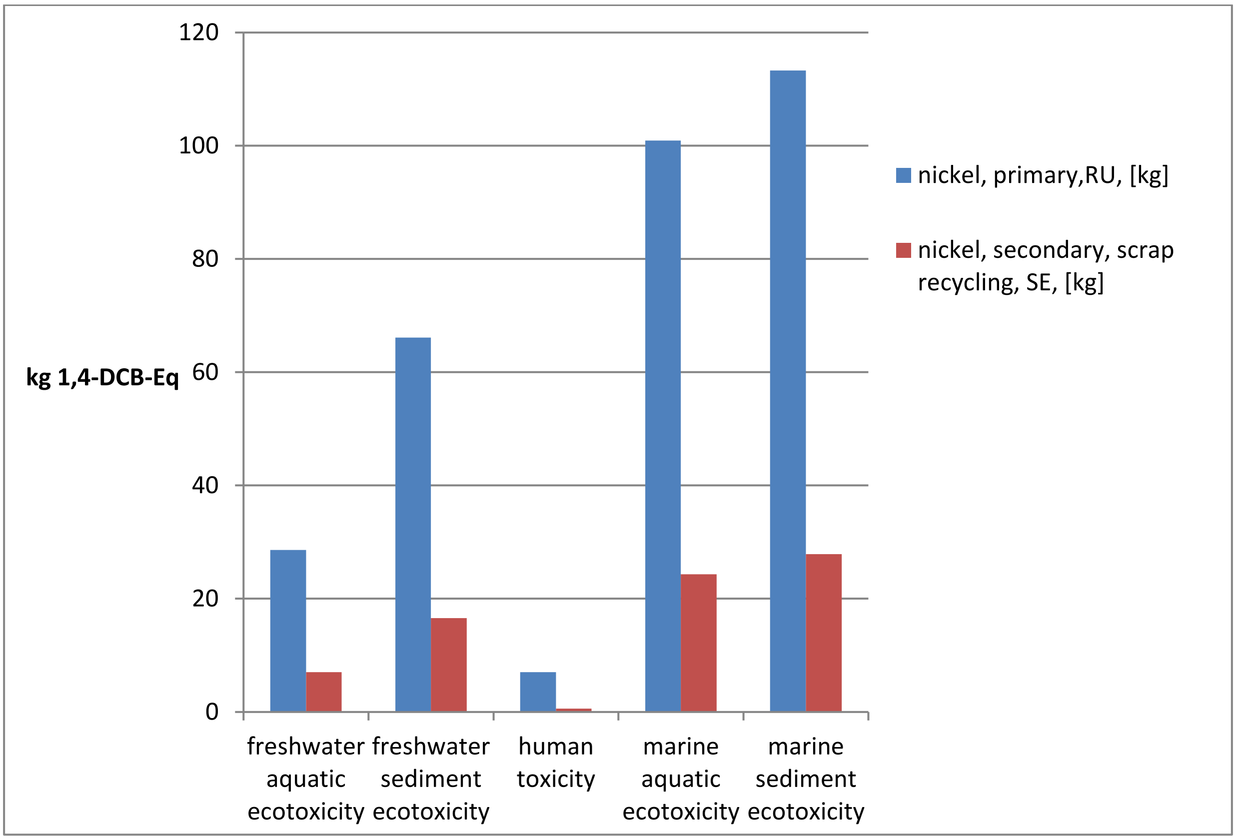

Figure 4.34: Ecotoxicity primary and secondary nickel production

Figure 4.37 presents the comparative analysis of nickel mined from ore and nickel recycled from electronic and electric scrap across five toxicity indicators based on the CML2001 method (Guinee, 2002). It can be seen that secondary nickel performs in a more environmentally friendly manner in all of the toxicity indicators.

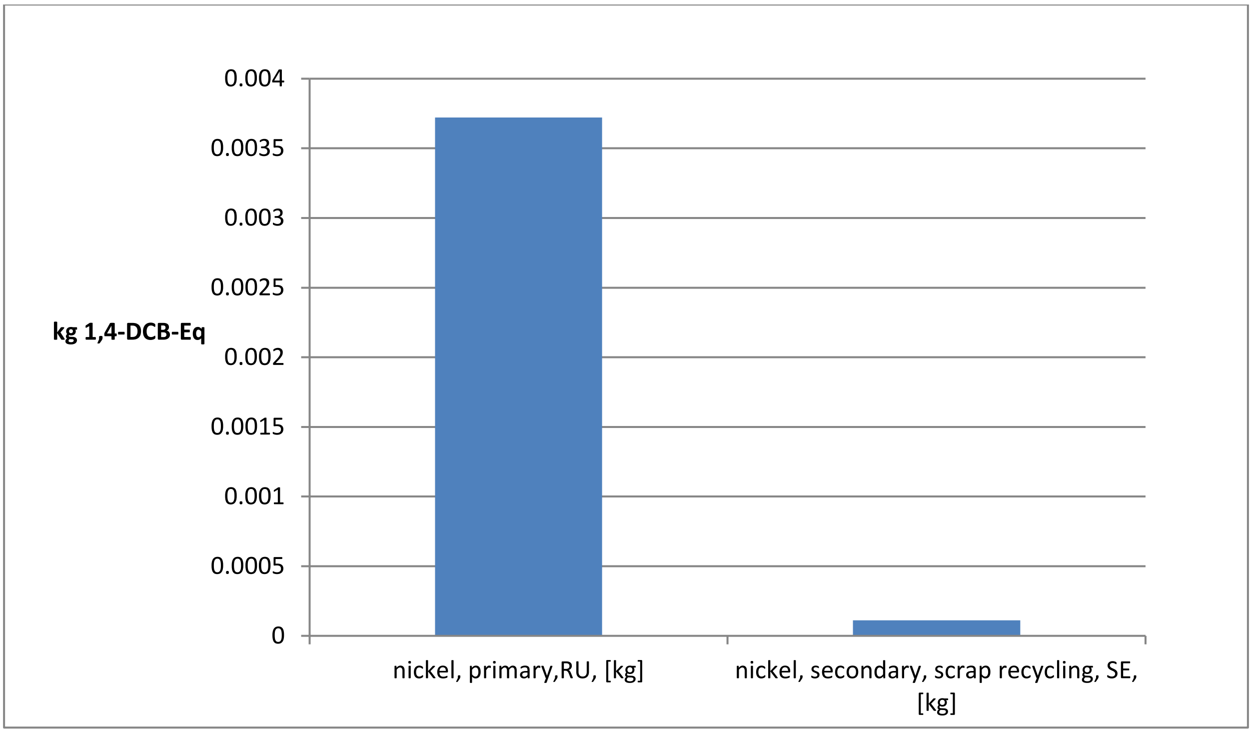

Figure 4.35: Terrestrial Ecotoxicity primary and secondary nickel production

Figure 4.38 presents the comparative analysis of nickel mined from ore and nickel recycled from electronic and electric scrap in terms of terrestrial ecotoxicity. The figures were too small compared to the first five ecotoxicity indicators to be shown on the same graph. However, the pattern is similar, with primary nickel performing much worse than recycled nickel from electric and electronic scrap.

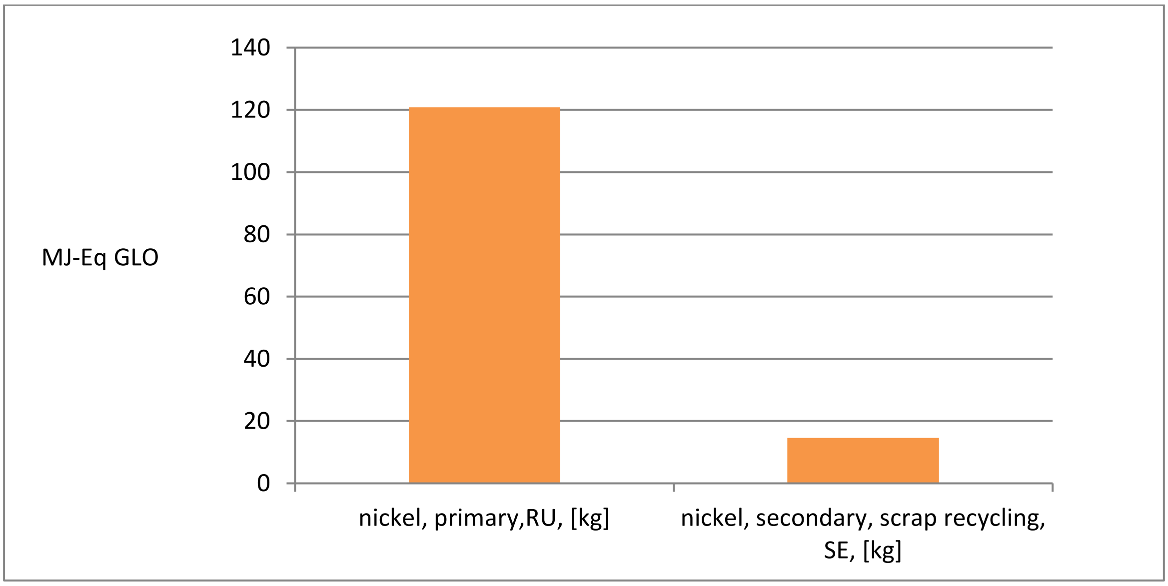

Figure 4.36: Cumulative energy demand for 1 kg of primary and secondary nickel.

Cumulative energy demand comparison between primary and secondary nickel production is presented in fig 4.39. Secondary nickel production used 14.55 MJ-eq of energy to produce 1 kg of lead compared to 120.89 MJ-Eq of energy needed to produce the same amount via primary production. In other words, secondary nickel uses only 12% of cumulative energy required for primary nickel production. Examining the Eco-indicator 99 impacts, it can be seen that primary Nickel also has significantly more impacts on the environment compared to secondary nickel, in terms of all three categories; ecosystem quality, human health and resources.

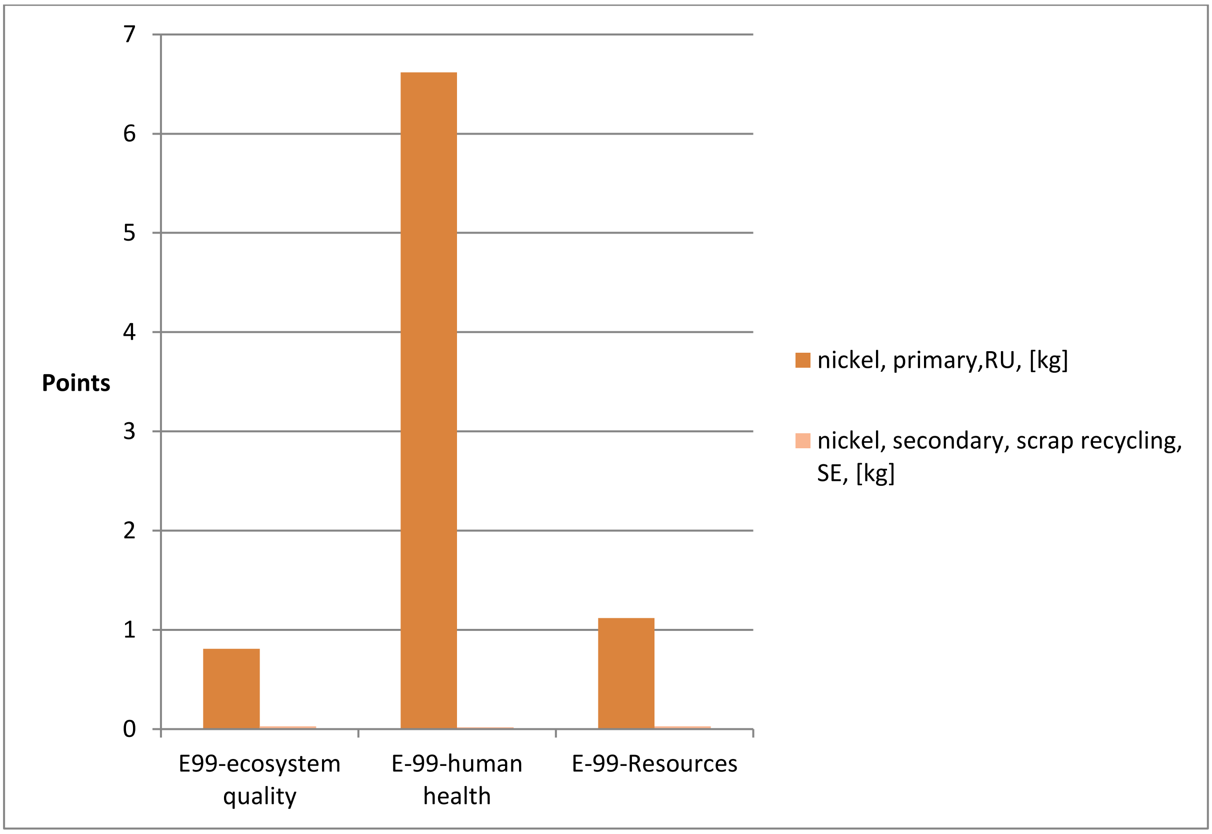

Figure 4.40: Eco-indicator 99 results for 1 kg of primary and secondary nickel

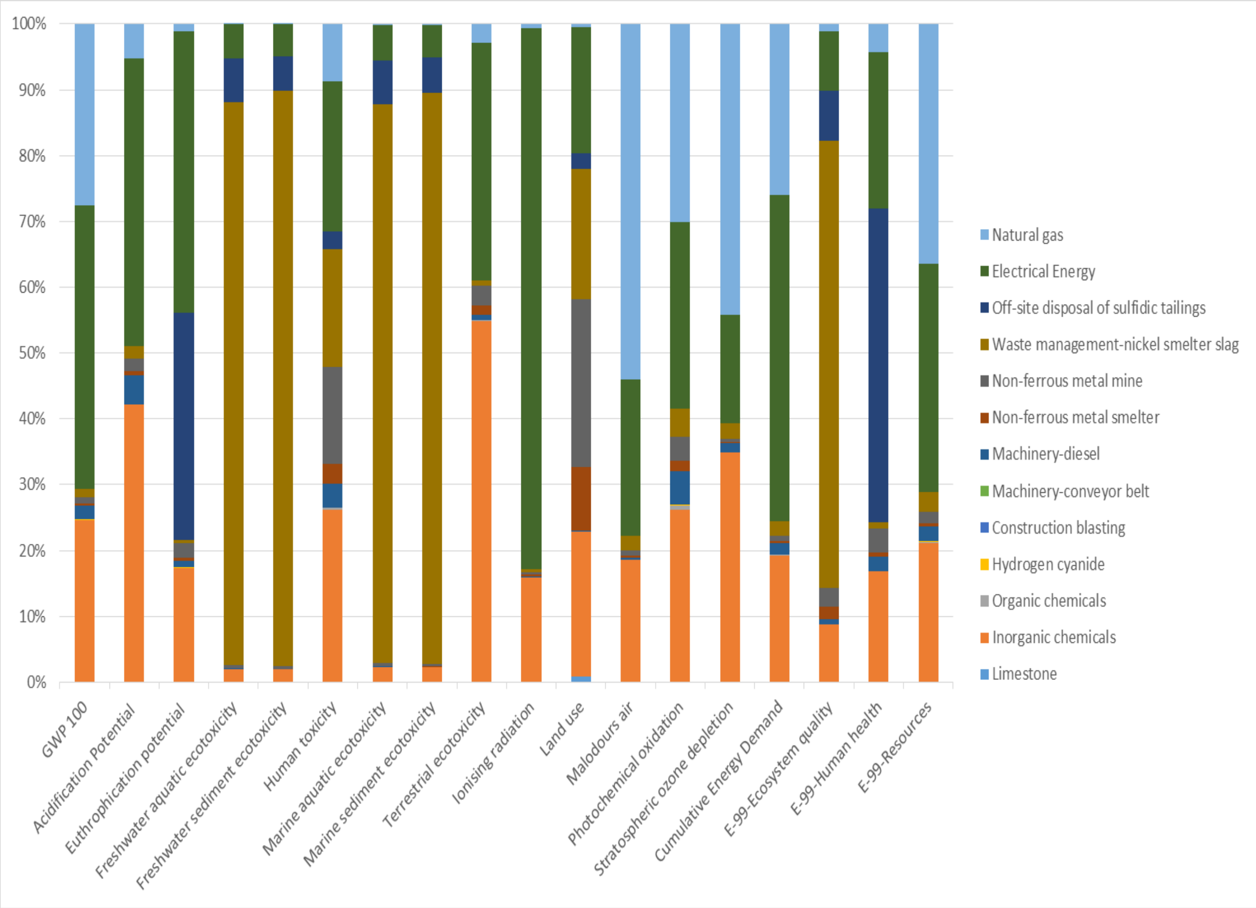

Figure 4.37: Environmental profile of 1 kg of Primary nickel showing relative proportions of each impact categories due to contributing processes.

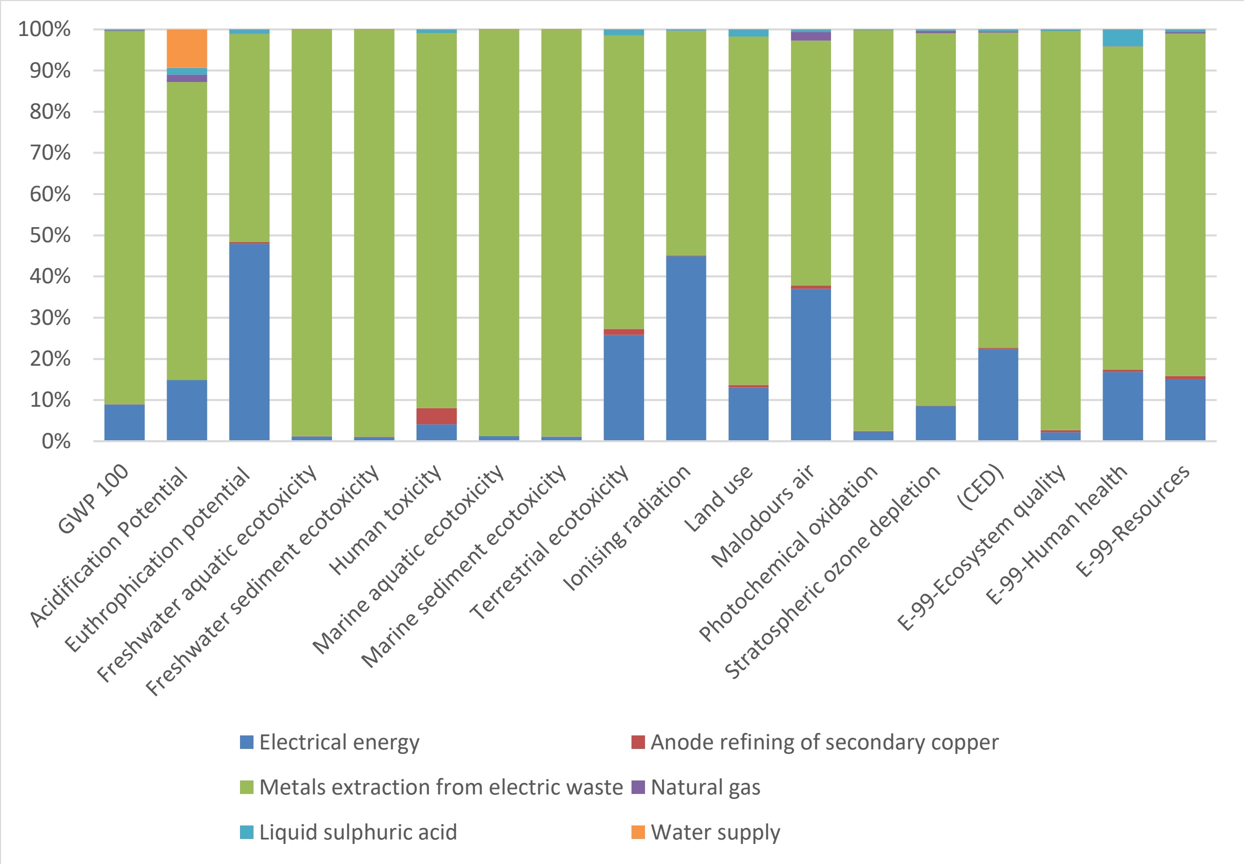

Figure 4.38: Environmental profile of 1 kg of secondary nickel showing relative proportions of each impact categories due to contributing processes.

4.3.3.4 Environmental profile of linear vs circular economy model of Nickel production

Figure 4.41 shows the environmental profiles of 1 kg of primary nickel. All impact indicators have been normalised and the total of each impacts equal to a 100%. In Fig 14, it is observed that electricity use is a major contributor to environmental impacts of primary Nickel production contributing most significantly 43% of global warming (GWP100), acidification (44%), eutrophication (43%) ionising radiation (82%), and cumulative energy demand (50%). Electricity contributes in some way to all impact indicators.

Furthermore, disposal of nickel slag to material landfill is also a main emissions contributor in the primary production of nickel after electricity use. This is due to the long-term emissions from landfill to ground water. Disposal of nickel slag accounts for fresh water aquatic ecotoxicity (85%), fresh water sediment ecotoxicity (87%), marine aquatic ecotoxicity (85%), marine sediment ecotoxicity (87%), and ecosystem quality (68%). The majority of human health impacts come from the disposal of sulfidic tailings which is makes up (48%). 35% of acidification potential is also attributed to the disposal of sulfidic tailings.

Natural gas used for heating purposes contributes a large proportion towards malodours air (54%), stratospheric ozone depletion (44%), resources (36%), and Photochemical oxidation (30%). Another significant contributor to environmental impacts is the inorganic chemicals used in the production process, accounting for acidification (42%), human toxicity (26%), terrestrial ecotoxicity (55%), and stratospheric ozone depletion (35%). Inorganic chemicals like contributes to all impact indicators. On the other hand, organic chemicals contribute the least to the majority of indicators.

Nickel is a vital metal in modern infrastructure and technology (Mudd, 2010), with a wide range of applications (Barnett, 2010). A detailed analysis of local issues pertaining to the mining of Ni is provided by Mudd (2010), where he submitted that although the environmental impact of Ni has improved across the years, its mining has resulted in serious historical local impacts including acid rain from SO_2 emissions, wetland acidification, soil contamination due to heavy metals, biodiversity loss (e.g. in fish populations). Nickel inhalation has been reported to lead to an increased risk of cancer in the lungs and noses of humans (Anttila et al., 1998).

Figure 4.42 shows the environmental profiles of 1 kg of secondary nickel. Nickel and other metals/materials extraction from electronic waste is the most significant contributor for all indicators in secondary nickel production. The extraction involves the conversion of Copper in a Kaldo Converter and treatment in converter aisle. The secondary scrap is refined in Boliden smelters. Leaching and high temperature reactions help to separate out the various metals. It contributed 91% of global warming (GWP100), acidification (72%), fresh water aquatic ecotoxicity (99%), fresh water sediment ecotoxicity (99%), marine aquatic ecotoxicity (99%), marine sediment ecotoxicity (99%), land use (85%), and acidification (59%). The lowest contribution of extraction from electronic waste was to eutrophication (51%), followed by ionising radiation (55%), and malodours air (59%).

In addition, the second most significant contributor to inventory impacts is electricity use. Electricity use contributes in some way to all impact indicators. Its highest contribution was eutrophication (48%) and ionising radiation (45%). From the Eco-indicator 99 impacts perspective, metal extraction from scrap contributes (97%) of ecosystem quality, human health (79%) and resources (83%). Lastly, examining the cumulative energy demand impact, it is found that (77%) of consumption goes to nickel and other metals/materials extraction from electronic waste with electricity making up.

4.3.3.5 Summary

Secondary nickel production from electric and electronic waste performs significantly better than primary nickel production from mining across multiple environmental performance indicators. The two differing production systems share a common hotspot which is electricity. Electricity use is the highest contributor to primary production while it is only the second highest contributor in secondary production. It is significant none the less. Metal prices make recycling an attractive venture. Secondary nickel production via the use of scrap saves energy use and is therefore more environmentally friendly.

4.3.4 Steel

Steel is an alloy of iron and carbon (World steel Association, 2016). Steel owes a lot its popularity to the low cost of making, forming and processing, the abundance of iron ore and scrap as well as its unequalled variety of mechanical properties (Wondris et al., 2016). Steel is essential to everyday life. It is an important component in the automotive and construction industry. It is used in cars, buildings, and transport infrastructure. World crude steel production was estimated to be 1621 million tonnes in 2015. The top ten producers of steel in 2015 were China with 803.8 million tonnes, making up nearly 50% of the world total followed by Japan, India, US, Russia, South Korea, Germany, Turkey and Ukraine.

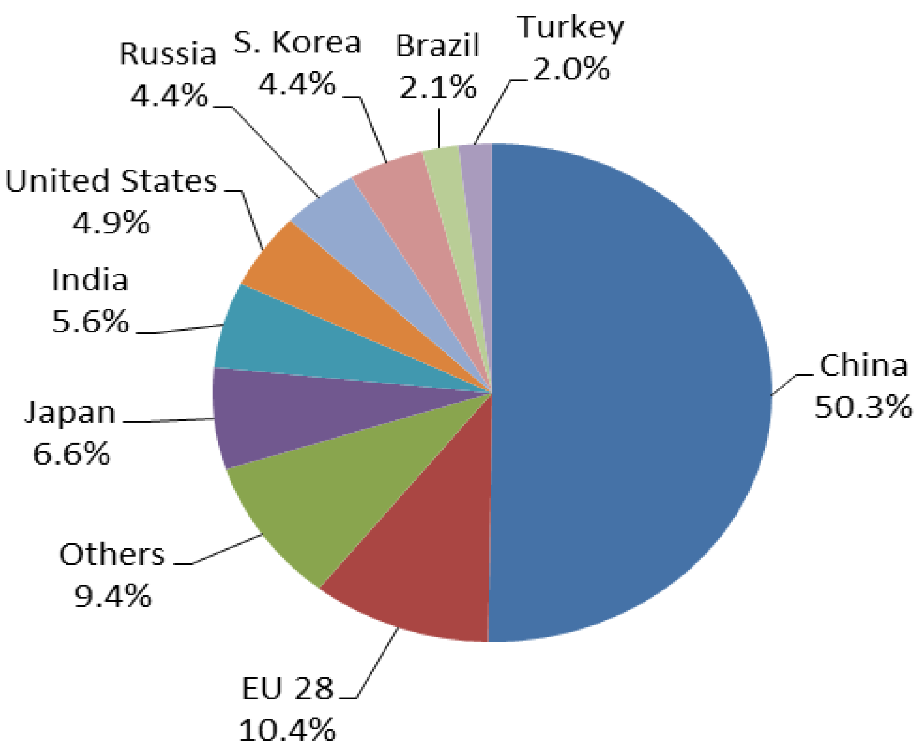

Figure 4.39: World Steel Production, 2015

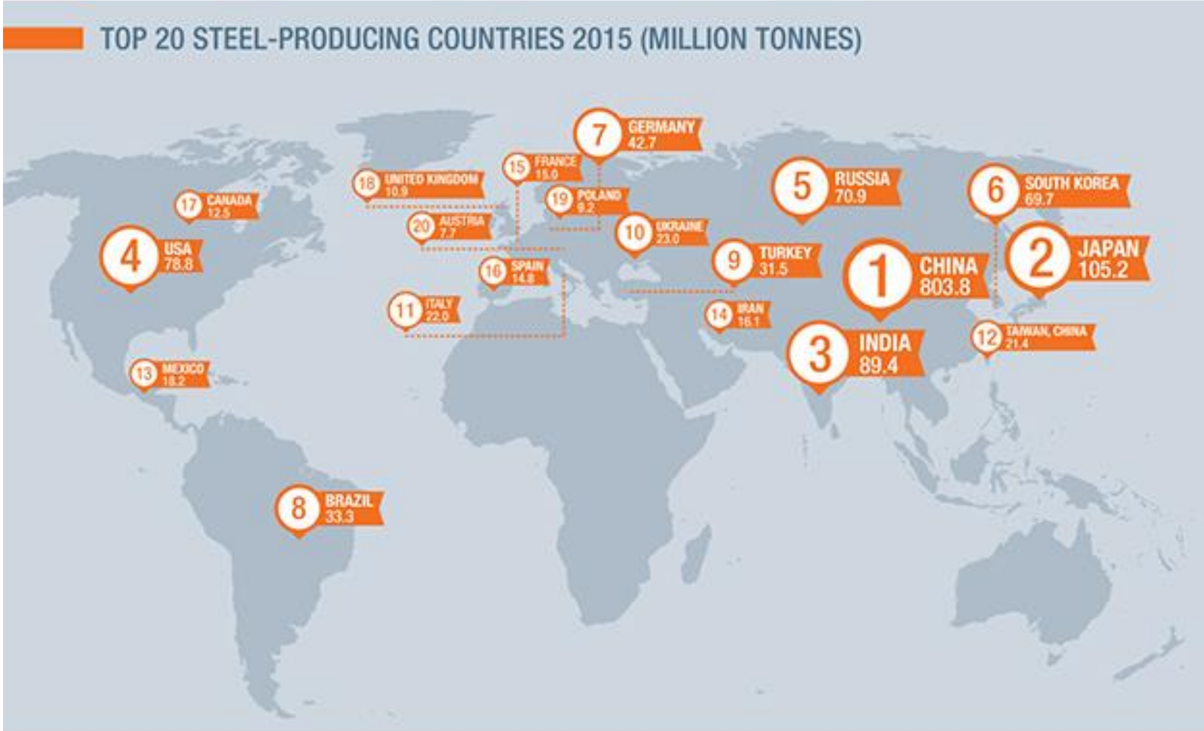

Figure 4.40: BF-BOF and EAF steel production and Secondary steel. Source: European Union

4.3.4.1 Primary steel Production (BF-BOF)

Primary steel Production is generally carried out through the blast furnace BF or basic oxygen furnace BOF route. The raw materials needed by this route are iron ore, coal, steel scrap. The BF-BOF route accounts for approximately 70% of world steel production. It begins with mining the iron ore. The mining involves explosives to blast the rocks in iron ore fields. The ores are then grinded into smaller pieces (pallets) in a grinder, from where the ore is separated using magnets. The ore is then heated to marble-sized pallets that will later be converted to iron. Coal is used to create coke that fuels the iron-making furnaces. Coal is crushed and sealed in air-tight ovens and is baked for a period. The coal is removed from the oven as solid carbon fuel. The fuel and pallets come together in the furnace with an addition of limestone to remove impurities. Elements such as phosphorus and silicon are present as impurities. Super-hot air combusts the coke. The process intensifies the heat and changing the raw materials into molten iron known as pig iron. The super-heated brew is tapped and moved in giant tanks to the basic oxygen furnace. Blast furnace gas and slag are by-products of the BF. The gas is used to generate electricity and the slag for concrete aggregates, pavements, cement replacement, graded road base etc.

Recycled steel scrap is dumped into the basic oxygen furnace and the hot iron is mixed in. high purity oxygen is blown into the mix at supersonic velocity, transforming molten iron into molten steel. The next stage is tapping the molten steel from the BOF vessel into a ladle then on to the vacuum degasser where the molten steel is made highly formable. The following stage is forming and finishing, casting, moulding. After casting and rolling, the steel is provided as slabs plates, sections or bars. The iron ores are reduced to iron through oxidation, slag, then removal of sulphur (desulfurization) and carbon (oxidation of carbon).

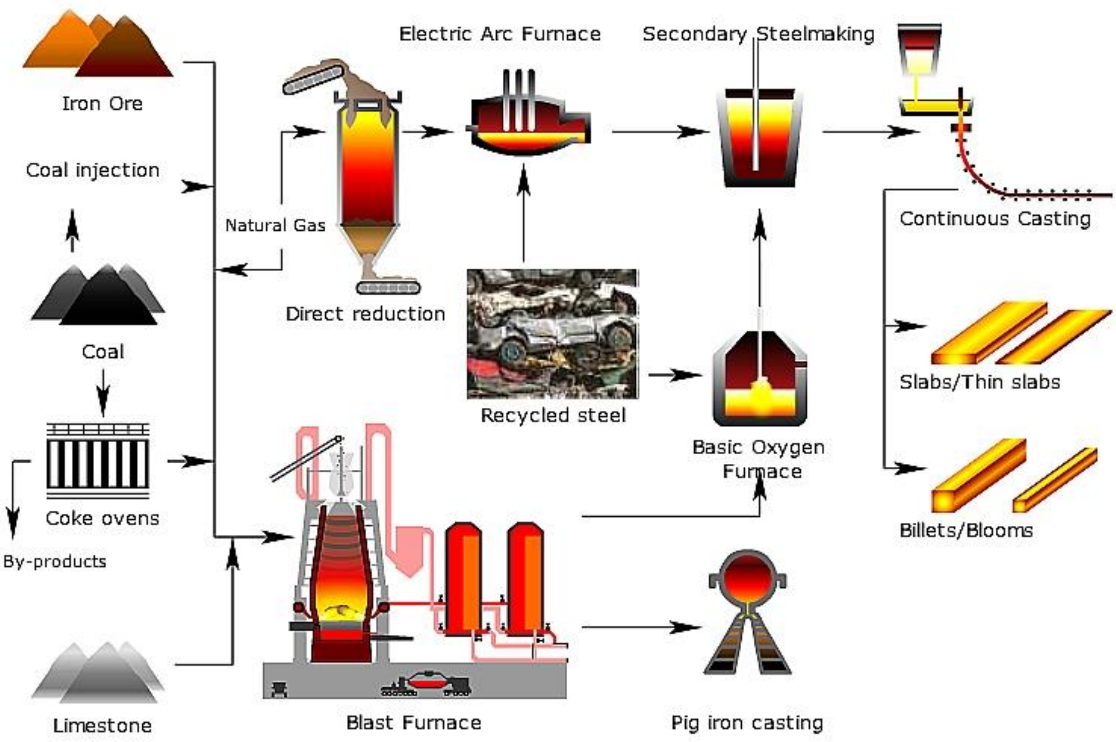

Figure 4.41: BF-BOF and EAF steel production (Source: http://www.sustainableinsteel.eu/)

4.3.4.2 Recycled steel scrap production (EAF)

Secondary steel Production is carried out through an electric arc furnace EAF. This route requires recycled steel scrap and electricity as the key raw materials. Oxygen and lime are added to bind any impurities. Recycled steel can be in the form of home scrap from excess material in steel facilities, industrial scrap from downstream production processes and obsolete scrap from discarded material. The EAF route can also make use of direct-reduced iron (DRI) or hot metal as additional sources of metallic iron, based on the plant configuration (World steel Association, 2016).

The electric arc furnace melts steel scrap and converts it into liquid steel of a specified chemical structure and temperature. The process starts with the metal scrap where heavy terrain machines sort the scrap according to weight. The scrap is transferred to the mill and is loaded using large electro magnets into a transfer bucket. The transfer bucket takes the scrap to the furnace for blasting in a charging bucket. The scrap is dumped in the charging bucket partially filled with previously melted steel, to keep the furnace continuously hot. As the scrap hits the charging bucket, the reaction is explosive, almost like extreme fireworks. This is an extremely hazardous part of steelmaking. Sometimes not all the scrap is melted, some junk metal remains at the top and there is a need for giant electrodes to turn up the heat. The electrodes are lowered into the furnace to deliver high voltages of electricity, further melting all previously unmelted scrap. The result is two materials; slag that floats to the top consisting of various impurities that did not vaporize in the heat such as aluminium and molten steel at the bottom.

The quality of slag determines the quality of recycled steel. Alterations are made to the recycled steel according the specification needed. The slag needs to be removed in a process called de-slagging, which is also a very hazardous process. The blast bucket is tilted and the slag is dumped out. The new steel is then tapped into a ladle. Once it cools, the new steel is shipped off for either secondary processing transported to the caster. This process is illustrated in fig 1. The EAF route starts in the middle with recycled steel and requires fewer steps and time to produce the end product unlike its BF-BOF counterpart. The EAF route is responsible for about one-quarter of the world’s steel. slabs of molten steel can then be produced using continuous casting for further processing, and the cast steel can be further processed into intermediate and final products using hot rolling (Gross and Perl, 2016).

4.3.4.3 Comparative analysis of linear vs circular economy model of steel production

The result shows that the carbon emissions from the supply chain of primary steel (BF-BOF) are 1.5753 kg CO_2-eq while that of secondary steel is 0.4217 kg CO_2-eq. The BOF emissions are is around a 273% higher than the EAF ones. It indicates that EAF steel production using a recycled steel scrap through a circular supply chain is significantly less carbon intensive than that of the steel produced using virgin materials through a linear production system.

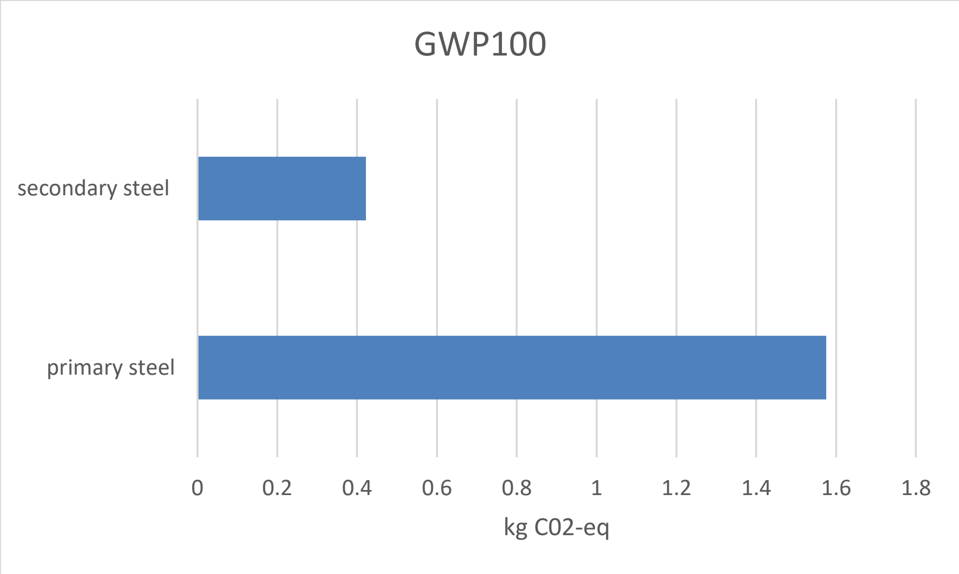

Figure 4.42: Comparative level of Carbon emissions by BOF and EAF steel routes.

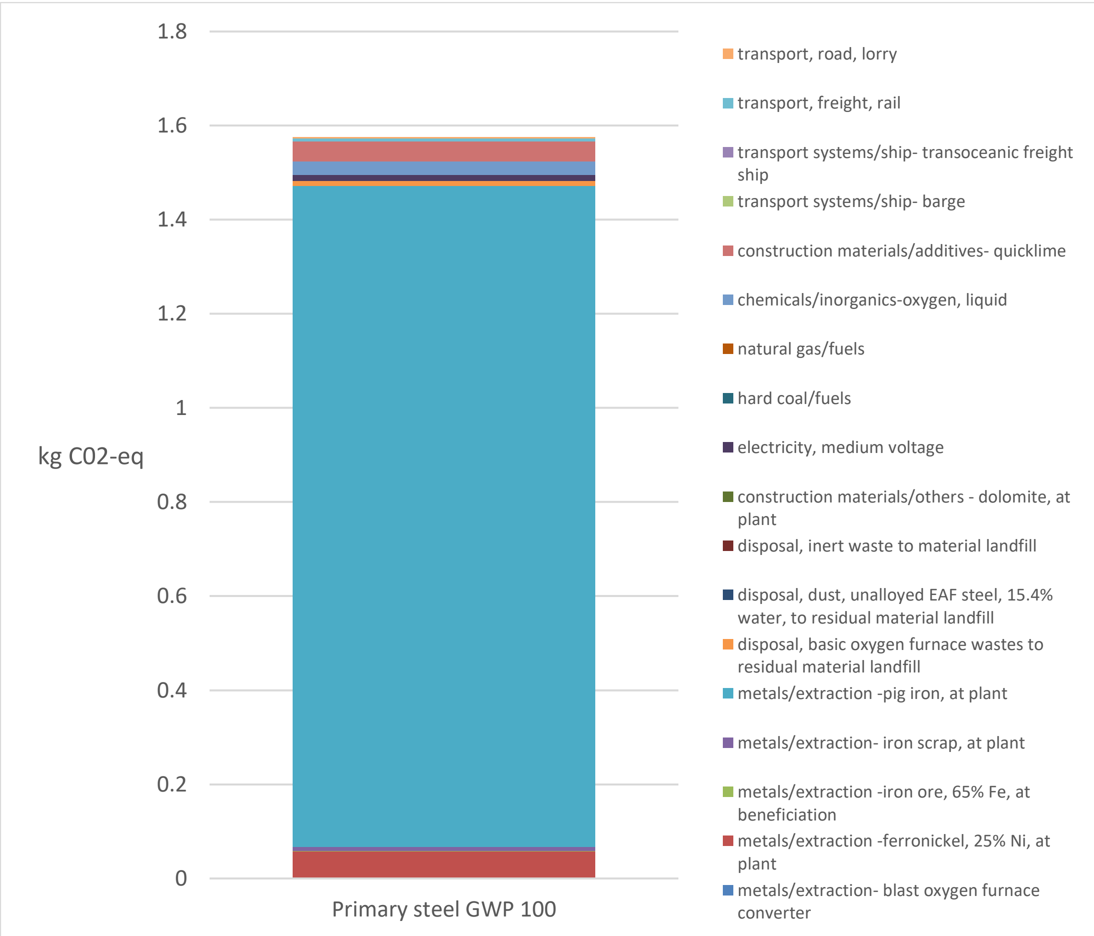

Figure 4.43: Breakdown of carbon emissions BF-BOF primary steel production

Figure 4.45, it is observed that metal extraction of pig iron in the blast furnace is the main carbon hotspot of primary steel production, contributing 89 % of total carbon emissions. The extraction of pig iron in the blast furnace requires iron ore and coke. The iron ore is smelted, using limestone as a flux. The resulting intermediate product is termed pig iron. Hard coal usages involve the combustion process and include softened water requirement, coal transport, ash disposal and electricity requirement. Ferronickel is also a significant carbon hotspot at 4%. Ferronickel is used as an alloying element. The next highest carbon emissions contributor is the additive limestone with emissions of 0.0418 kg CO_2-eq, contributing 3 % of total carbon emissions. Limestone is used as a slag former, also helps maintain the refractory life of furnaces. The rest of inputs contribute not more than 2% each respectively.

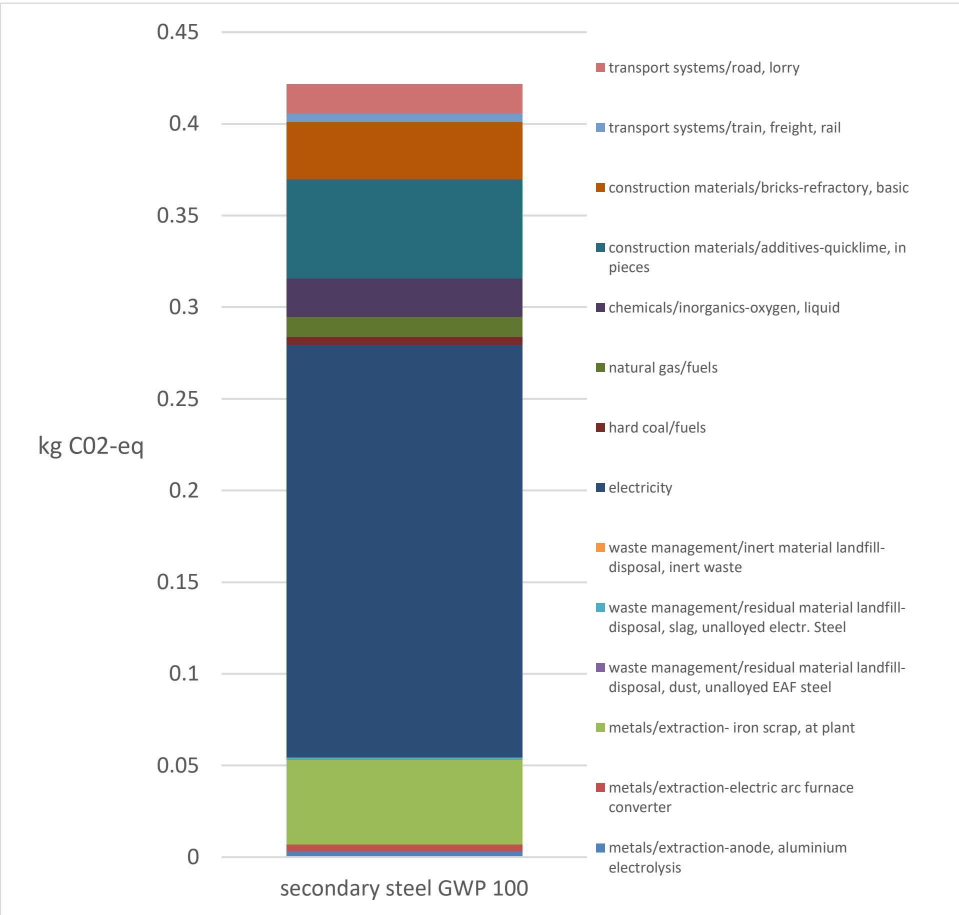

Figure 4.44: Breakdown of carbon emissions for EAF steel production

From Figure 4.48, it is observed that electricity use is the main carbon hotspot of EAF steel production. It contributes 53 % of total carbon emissions. This is understandable because a huge amount of electricity is needed to heat the furnace and melt the scrap into new steel. This is followed by quicklime, contributing 13 % of total carbon emissions, used as a flux agent to efficiently and effectively remove impurities such as phosphorus, silica and alumina from scrap melting. Scrap iron and steel feedstock are key raw materials in EAF steel production, with emissions of 0.0465 kg CO_2-eq, accounting for 11 % of total carbon emissions.

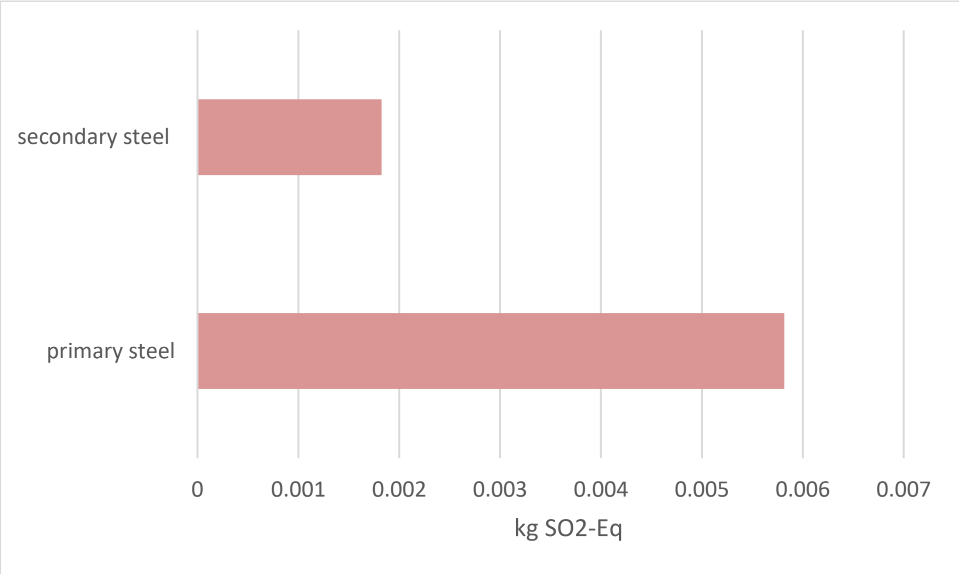

Figure 4.45: Acidification potential by BOF and EAF steel routes

Figure 4.49 compares the acidification potential for both BF-BOF primary steel production and EAF recycled-steel production. From the graph, EAF recycled-steel production performs better than BF-BOF primary steel production. EAF recycled-steel production is responsible for 0.0018 kg SO_2-Eq compared to 0.0058 kg SO_2-Eq caused by BF-BOF primary steel production, equating to an estimated 222.2% increase between the two routes.

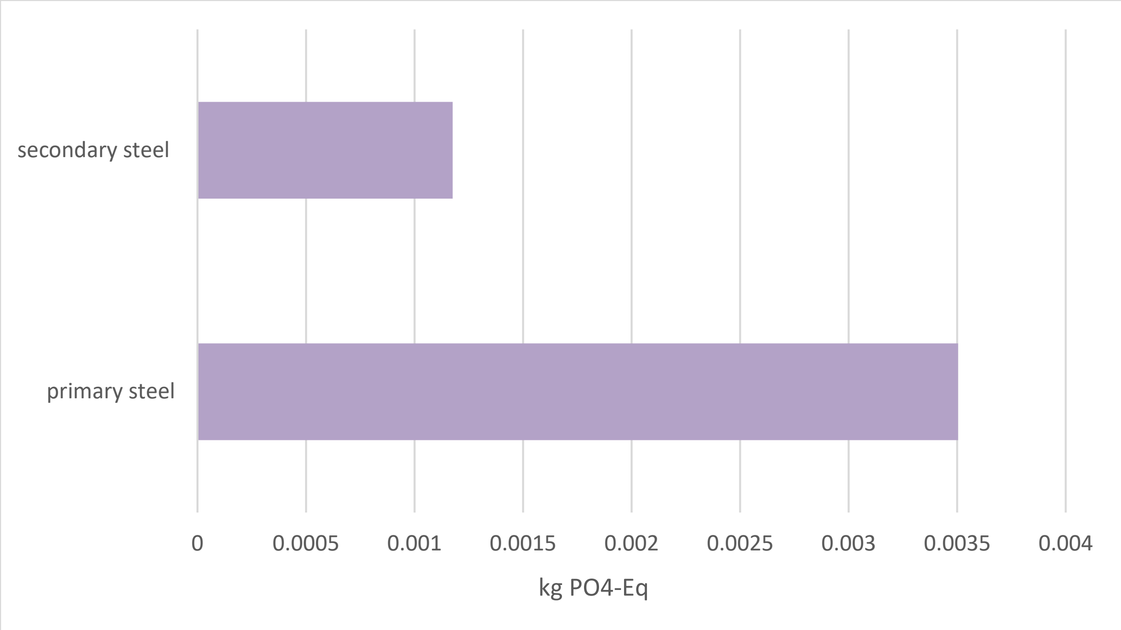

Figure 4.46: Eutrophication potential of by BOF and EAF steel routes

The breakdown of eutrophication potential for both BF-BOF primary steel production and EAF steel production is presented in Figure 4.50 It can be observed from the graph that BF-BOF primary steel production (0.0035 kg PO_4-Eq) contributes significantly more than EAF scrap steel production (0.0012 kg PO_4-Eq) in terms of eutrophication potential.

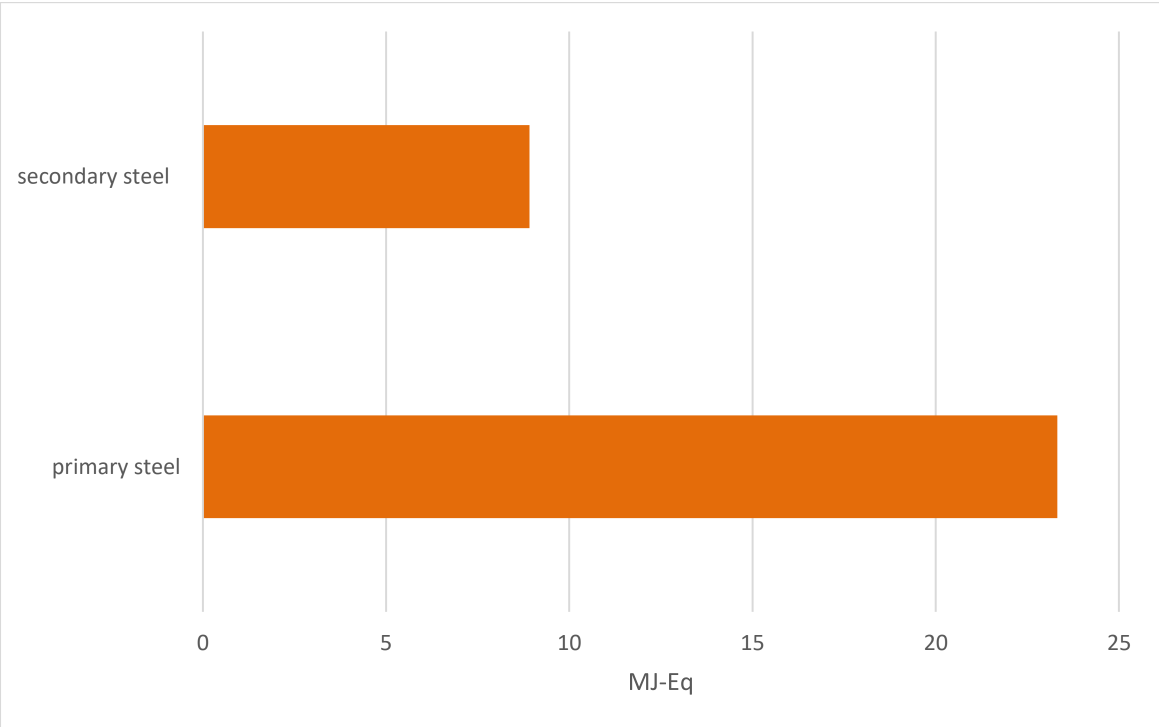

Figure 4.47: Cumulative energy demand of BOF route compared to EAF steel route

Figure 4.51 compares cumulative energy demand between BF-BOF primary steel production and EAF recycled-steel production. EAF steel production uses 8.9137 MJ-Eq of energy compared to 23.3238 MJ-Eq of energy used in BF-BOF primary steel production. In other words, approximately 161.66% more cumulative energy is required for BF-BOF primary steel production than for EAF recycled-steel production.

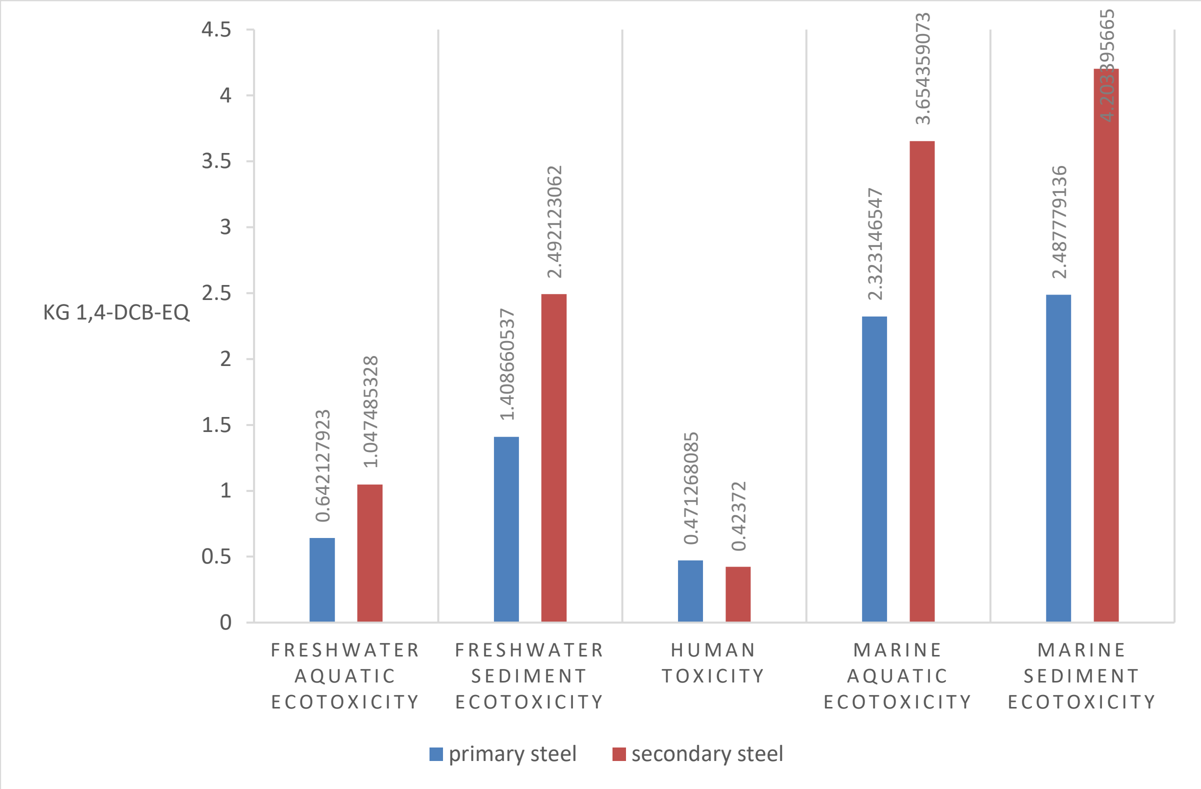

Figure 4.48: Toxicity by BOF vs EAF steel routes

Figure 4.52 shows the comparative analysis of BF-BOF primary steel production and EAF recycled-steel production across five toxicity indicators based on the CML 2001 method (Guinee, 2002). It can be seen that BF-BOF primary steel production is more environmentally friendly in all of the toxicity indicators except human toxicity. This can be attributed to the disposal of dust and slag from the EAF. The dust consists of a mixture of zinc, lead and iron oxides and small amounts of chrome, nickel and manganese, which are hazardous to human health. The dust and slag cause short-term emissions to water from leachate as well long-term emissions from landfill to ground water.

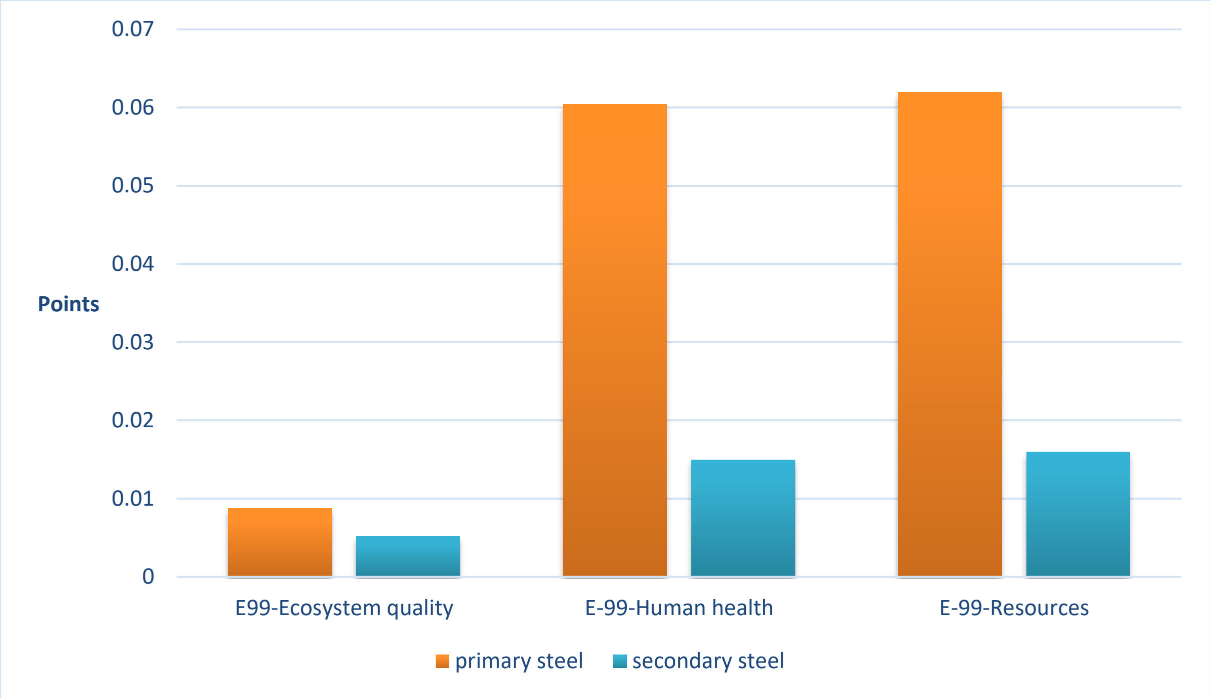

Figure 4.49: E-99 Indicators comparison by BOF vs EAF steel routes

In terms of Eco-indicator 99 impacts (shown in Figure 4.53) that comprise ecosystem quality, human health and resources, EAF recycled- steel production has significantly less impacts on the environment compared to BF-BOF virgin steel production through iron ore mining.

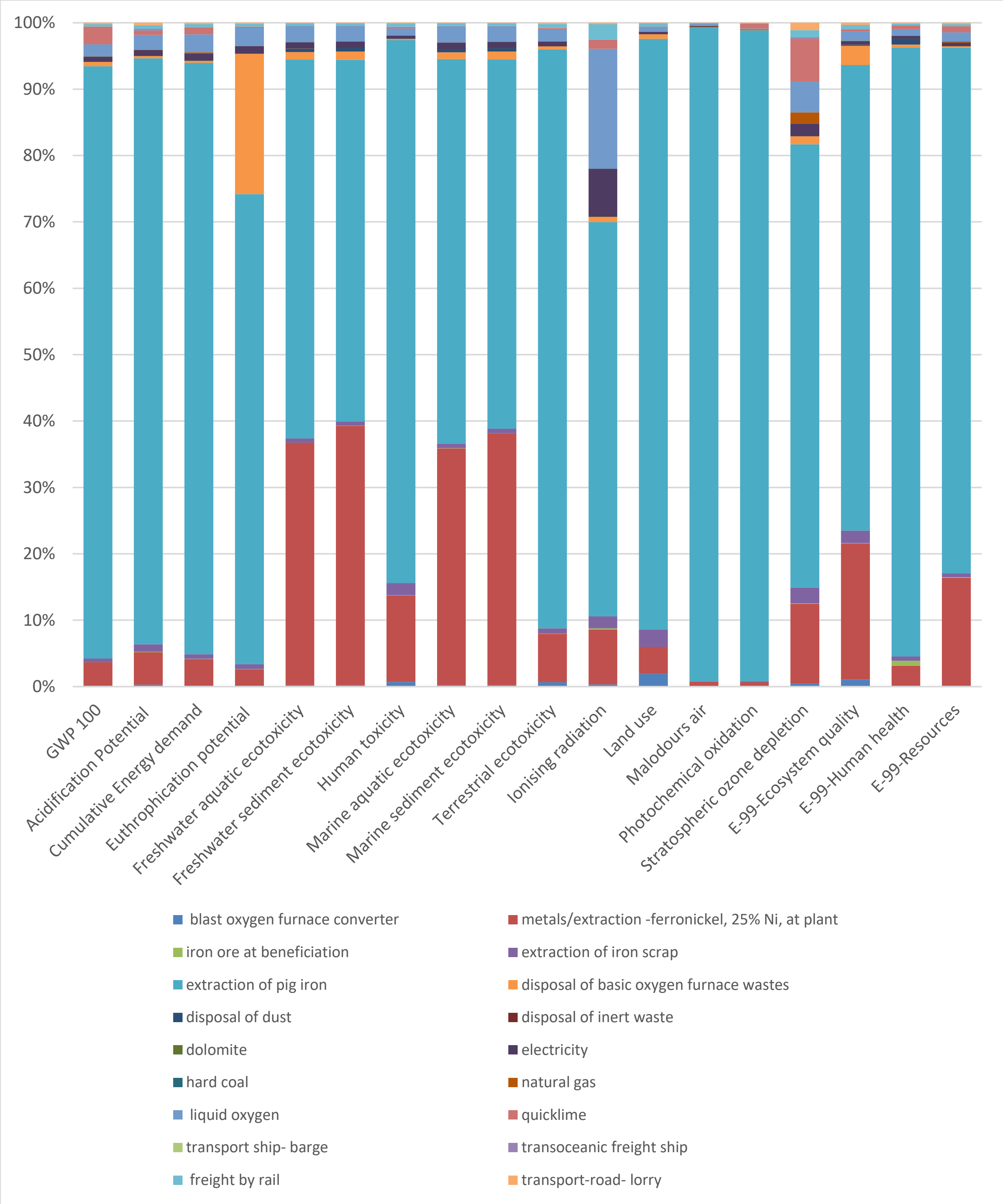

Figure 4.54: Environmental profile of BF-BOF steel showing relative proportions of each of the impact categories due to contributing processes.

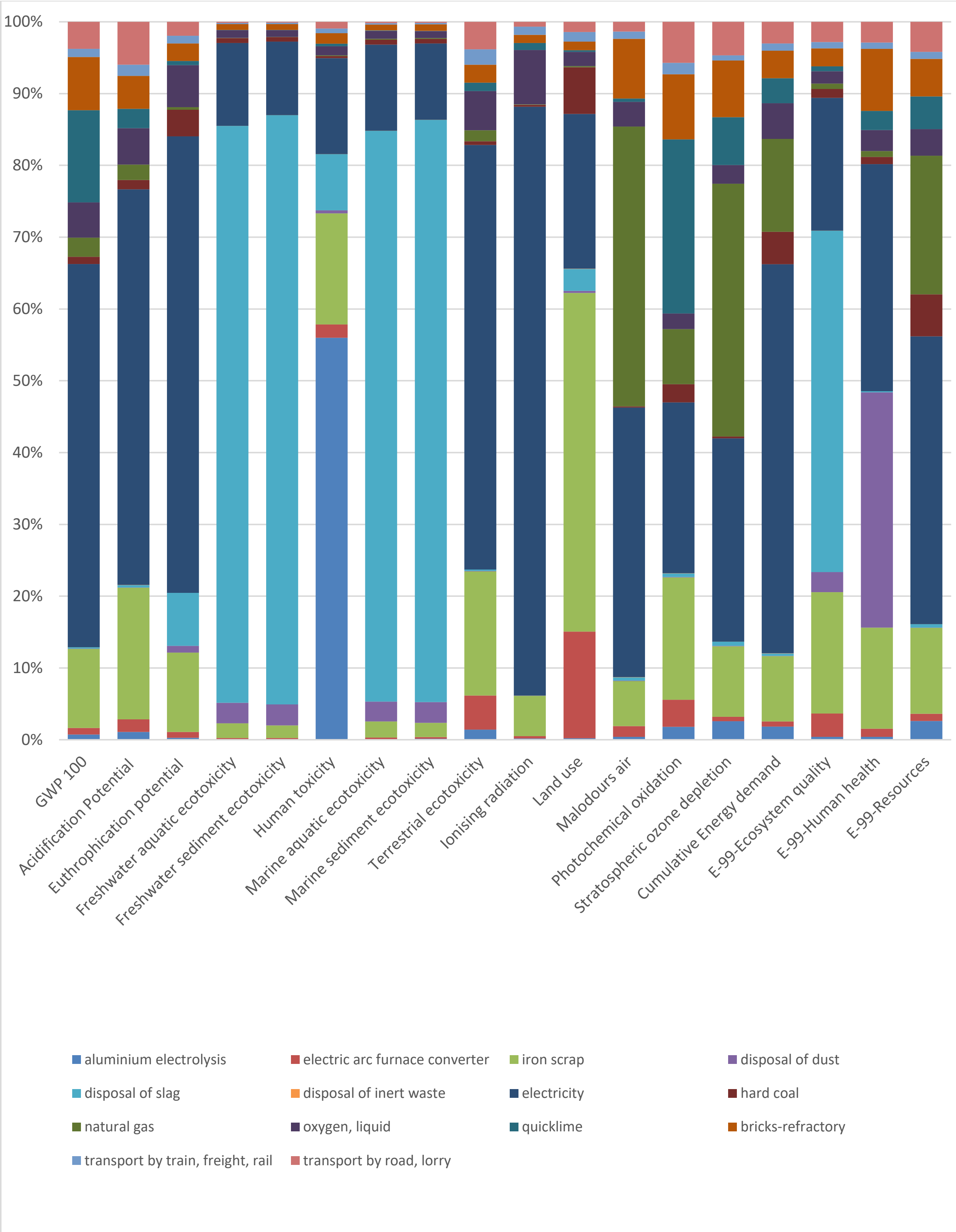

Figure 4.50: Environmental profile of EAF steel showing relative proportions of each of the impact categories due to contributing processes.

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4.3.4.4 Environmental profile of primary and secondary steel

Figure 4.54 shows the environmental profile of BF-BOF steel production. All impact indicators have been normalised and the total of each impacts equal to a 100%. It can be seen that metal extraction of pig iron in the blast furnace is a major contributor to environmental impacts of BF-BOF steel production. The extraction of pig iron in the blast furnace requires iron ore and coke. The iron ore is smelted, using limestone as a flux. The resulting intermediate product is termed pig iron. It contributes most significantly 89% of global warming (GWP100), acidification (88%), eutrophication (43%), ionising radiation (82%), cumulative energy demand (89%), photochemical oxidation (98%), malodours air (98%), human toxicity (82%), and land use (85%). Its lowest contribution was fresh water sediment ecotoxicity (55%). Metal extraction of pig iron contributes in a large proportion to all impact indicators.

Furthermore, Ferronickel used as an alloying element is also a main emissions contributor in BF-BOF steel production. Ferronickel use accounts for fresh water aquatic ecotoxicity (37%), fresh water sediment ecotoxicity (39%), marine aquatic ecotoxicity (36%), marine sediment ecotoxicity (38%), ecosystem quality (21%). resources (16%), and human toxicity (13%). Figure 4.55 shows the environmental profiles of 1 kg of EAF steel production showing relative proportions of each of the impact categories due to contributing processes. Electricity use is the most significant contributor for all indicators in EAF scrap steel production. Extremely high voltage of electricity is needed to heat the furnace and melt the scrap into new steel while also removing impurities. Electricity use contributes 53% of global warming (GWP100), acidification (55%), eutrophication (64%), terrestrial ecotoxicity (59%), ionising radiation (82%), and cumulative energy demand (54%). The lowest contribution of electricity use was to fresh water sediment ecotoxicity (10%), followed by marine sediment ecotoxicity (11%), fresh water aquatic ecotoxicity (12%), marine aquatic ecotoxicity (12%), and human toxicity (13%).

In addition, another significant contributor to inventory impacts is waste management particularly the disposal of slag to material landfill. Slag causes short-term emissions to water from leachate as well long-term emissions from landfill to ground water. Its highest contribution was fresh water sediment ecotoxicity (80%), fresh water aquatic ecotoxicity (82%), and marine aquatic ecotoxicity (80%), followed by marine sediment ecotoxicity (81%), and ecosystem quality (48%). Lastly, scrap iron and steel contribute to environmental impacts 11 % of total carbon emissions. Scrap iron and steel feedstock are key raw materials in EAF steel production. Scrap iron and steel contributes in some way to all impact indicators. It contributes land use (47%), acidification (18%), terrestrial ecotoxicity (17%), ecosystem quality (17%) and photochemical oxidation (17%).

4.3.4.5 Summary of steel analysis

EAF recycled- steel production performs significantly better than BF-BOF steel production from iron ore mining in key environmental performance indicators; global warming potential (GWP100), acidification (88%), eutrophication and cumulative energy demand. BF-BOF steel production outperforms in all of the toxicity indicators except human toxicity. Metal extraction of pig iron in the blast furnace is the highest contributor to BF-BOF steel production electricity use is the highest contributor in EAF production. Metal prices make recycling an attractive venture. EAF recycled- steel production via the use of scrap saves energy use, while also diverting metal scrap from landfill and incineration and is therefore more environmentally friendly.

4.4 The case for co-production

LCAs of linear production do not include allocation among the co-products: For instance, Copper and Nickel could be mined together, so also copper and lead (Biswas et al., 2002; Mudd, 2010; Mistry et al., 2016). Minerals and minerals ores are aggregates of different metals and chemicals that could be extracted and refined together to minimize costs and impacts. The combined production of copper is examined below across a few notable environmental sustainability indicators. Figures 4.54-57 illustrate carbon emissions, Acidification potential, Eutrophication potential and Cumulative energy demand for copper production according to four different routes namely linear production from mining copper alone, linear combined mining of copper with zinc-lead-gold-silver, circular production from electronic and electric scrap recycling and lastly circular production from high quality processed scrap that does not include the collection, sorting and cleaning of the copper scrap (Ecoinvent, 2017). Combined production brings down the carbon emissions, Acidification potential, Eutrophication potential of linear production much closer to normal circular production from scrap. It is only in the case of cumulative energy demand that the co-production of copper with other metals doesn’t have a positive impact. It is fair to say that there is a positive case for co-production of metals that are found as aggregates in terms of some key environmental indicators.

In this chapter, a detailed analysis regarding the comparison between linear and circular economy using representative metals within the metal sector is provided. The analysis provided across all case studies demonstrated the competitive edge of circular economy over the linear approach, at least from a purely environmental perspective. Additional work on polystyrene found in the appendix also highlights the benefits of circular production through recycling over linear production from an environmental point of view.

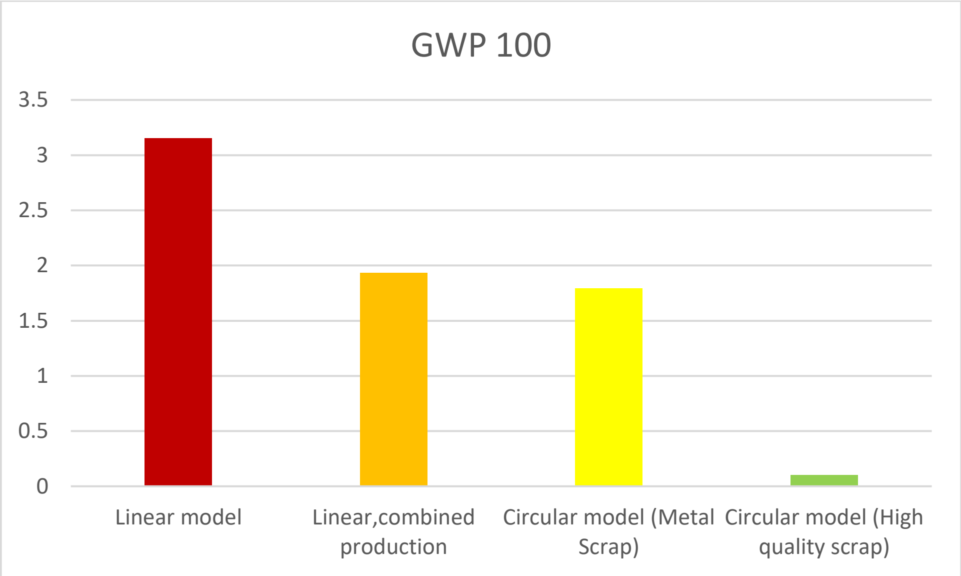

Figure 4.51: Comparative carbon emissions of between two linear approaches and two circular economy models

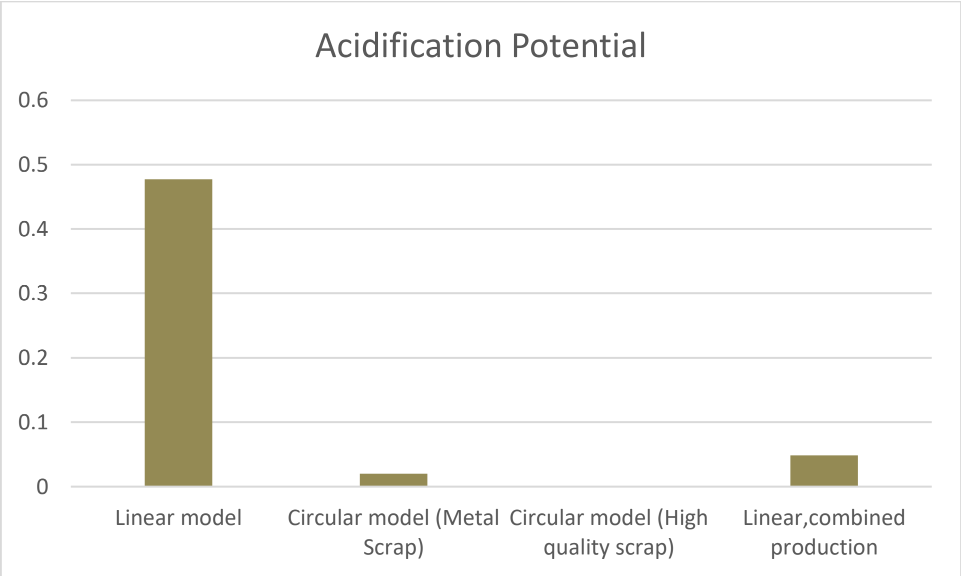

Figure 4.52: Comparative Acidification potential between two linear approaches and two circular economy models of copper production

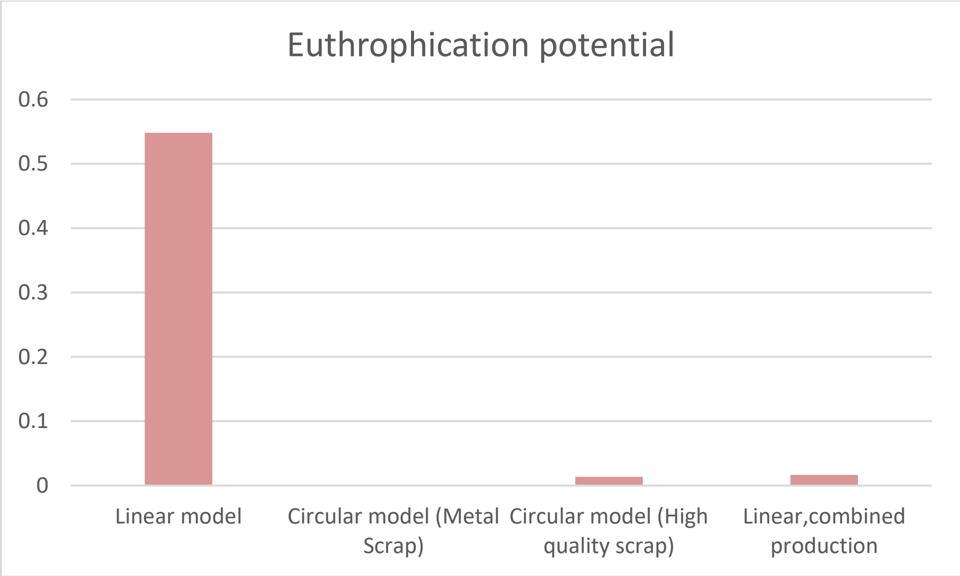

Figure 4.53: Comparative Eutrophication potential between two linear approaches and two circular economy models of copper production

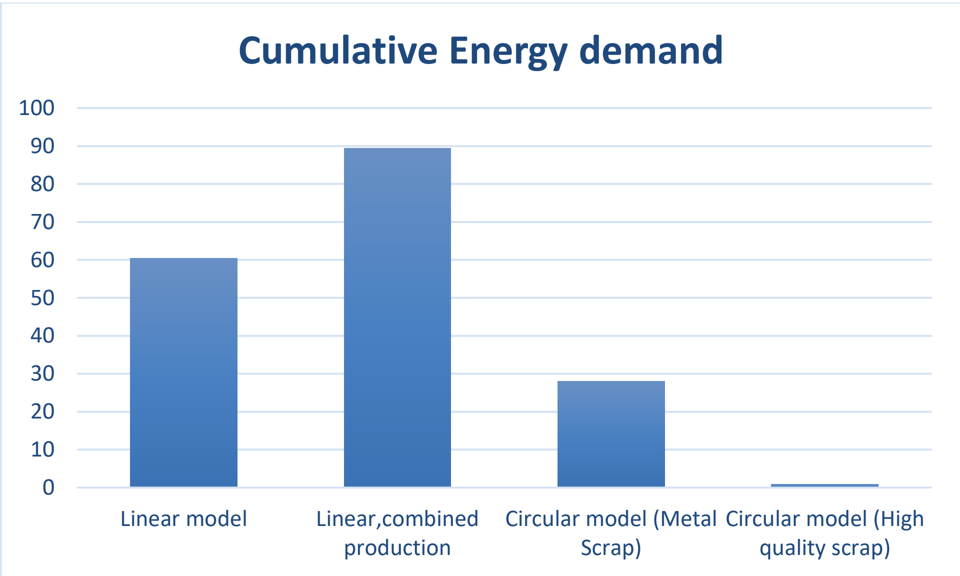

Figure 4.54: Cumulative energy demand for between two linear approaches and two circular economy models of copper production.

4.5 Additional work

Additional work on polystyrene found in the appendix also highlights the benefits of circular production through recycling over linear production from an environmental point of view.

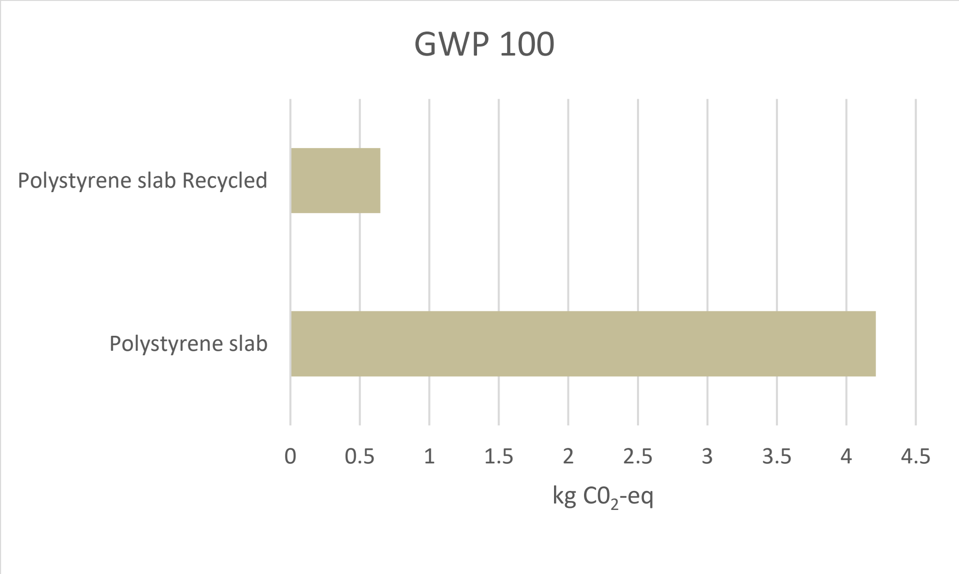

Figure 4.60: Comparative level of Carbon emissions by PS and PS-recycled.

The result shows that the carbon emissions from the supply chain of polystyrene are 4.2121 kg CO2-eq while that of polystyrene slab-recycled is only 0.6472 kg CO2-eq. The results are similar for other key indicators including acidification potential, eutrophication potential and cumulative energy demand, providing valuable confirmation in favour of circular economy advantages. Other examples from the food industry and the construction sector support this finding. (Genovese et al., 2015; Nasir et al., 2017). Please refer to Appendix B.

4.6 Chapter summary

In this chapter, a detailed analysis regarding the comparison between linear and circular economy using representative metals within the metal sector is provided. The analysis provided across all case studies demonstrated the competitive edge of circular economy over the linear approach, at least from a purely environmental perspective. In the chapter that follows, a detailed analysis of the views and perceptions of key stakeholders within the metal sector is presented.

Chapter 5: Analysis and discussion of Stakeholder's views on transitions towards a circular economy

5.1 Introduction

In chapter four, a detailed analysis and discussion of the competitive edge of circular economy over the linear economy using representative metals (i.e. steel, copper, nickel and lead) within the metal and fabricated sector was presented. For all cases presented, the case for the transitioning towards a circular economy using lifecycle analysis framework within multi-metric sustainability indicators, was demonstrated. Essentially, adopting a circular economy towards a sustainable and low-carbon economy will be a worthwhile endeavour when adopted holistically. However, despite the assurances and competitive edge presented by circular economy in terms of its ability to transform waste into resources whilst bridging the gap between production and consumption activities, the embrace of the concept into the mainstream decision making is still a difficult proposition. This therefore prompted a rigorous interview session with key stakeholders with the view to explore their perceptions, views, experiences, beliefs and disposition towards the move to circular economy and determine in a systematic fashion the factors or drivers limiting its adoption despite the clear advantages and opportunities it offers. This chapter therefore presents the results and analysis from the qualitative data collected from the stakeholders through interviews.

To put the chapter and its content into perspective, it is important to have an understanding of a typical supply chain of metals using a product derived from one of the key metals considered in this research. Accordingly, Figure 5.1 depicts the supply chain of lead-batteries detailing sustainability issues including climate and energy, land and ecosystems, health, safety and rights as well as environmental hotspots. As shown, the supply chain takes the form of cradle-to-grave from resource extraction (i.e. mining of lead metal), component manufacturing, and lead-acid manufacturing down to end-of-life scenarios such as final disposal and recycling. The understanding derived from the supply chain diagram shown in Figure 5.1 assist in formulating key decisions regarding the type of stakeholders to consider for the examination of circular economy paradigm as it pertains to the metal industry. It also assisted in ascertaining the characteristics that each of the identified stakeholders must possess before they can be adjudged satisfactory before their opinions are adopted to shape the overall understanding of the concept of circular economy. In the section that follows, a description of the identified key stakeholder for the study is provided.

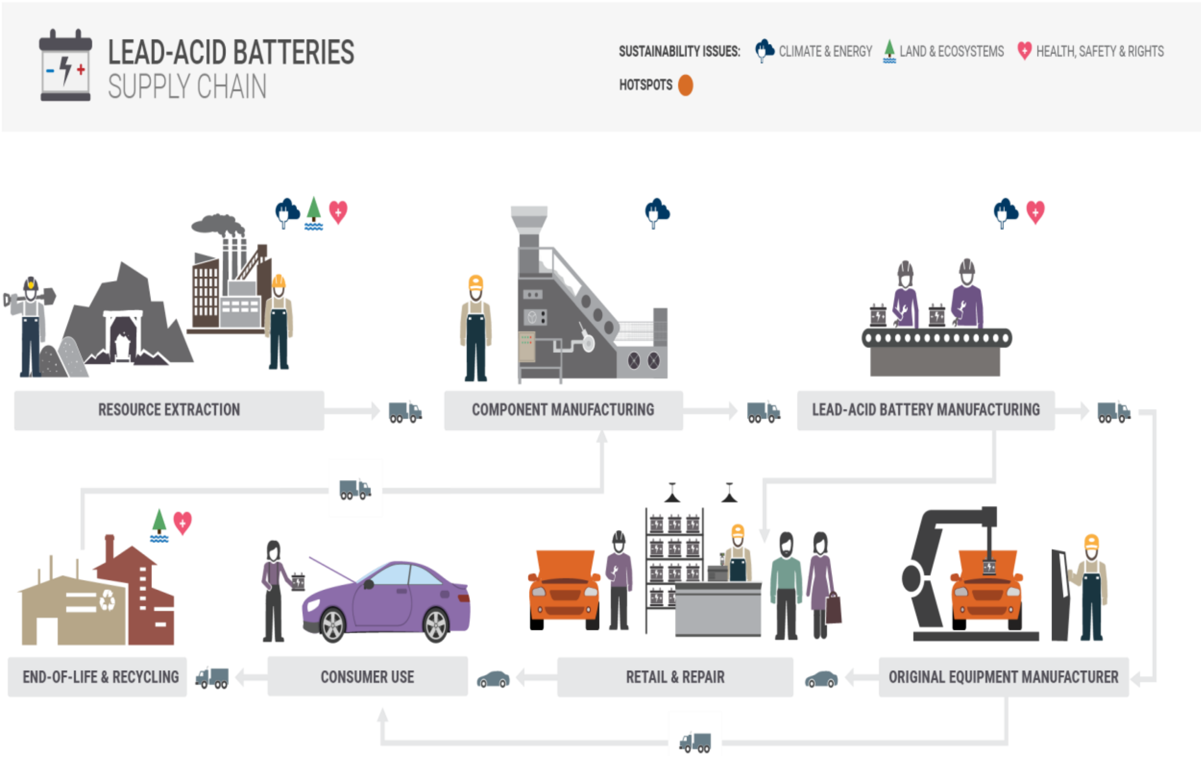

Figure 5.1: Typical supply chain of lead-acid batteries. Source: (The Sustainability Consortium, 2017)

5.2 Stakeholder identification and criteria for selection

Figure 5.2 provides a schematic diagram detailing the stakeholders within the metal supply chain. They include different stakeholders such as primary producers of metals, consumers, scrap dealers, local councils, waste collectors, sustainability officers/managers, environmentalists, academics, energy policymakers, investors, and civil society. The identification and selection of key stakeholders for the interviews was based on certain vital criteria. The stakeholders include individuals, professionals and experts that are (i) are affected directly or indirectly by activities of other stakeholders within the industry; are currently and demonstrably active in the metal industry, energy and sustainability issues; (ii) familiar with key characteristics of the supply chain of the metal and fabricated metal industry; (iii) familiar with and understand the principles of circular economy and the importance of transitioning towards it; (iv) able to influence decision making in the quest towards a circular economy; (v) familiar with issues of climate change, energy and sustainability issues; (vi) familiar with the use of LCA as a computational tool for tracking emissions from cradle to grave which can then serve as a tool for identifying opportunities in circular economy paradigm; and (vii) possess first-hand working knowledge of UK and EU-wide policies regarding the metals industry. It should be noted that the stakeholders did not have to meet every single criterion to be considered. For instance, not all participants had background knowledge of the circular economy concept such as household consumers of metal products but met the first criterion. However, the industry experts and academics had significant knowledge on LCA and the concept of circular economy and thus met more one criterion.

Interviewees were asked to identify other stakeholders part of the interview process. This process of stakeholder identification was repeated until it was considered that the complete stakeholder network had been established. However, not every stakeholder that had been identified was interviewed, though every effort was made to encourage participation by identified stakeholder groups. Non-participation by some stakeholders is discussed more fully in the limitations section in the conclusion chapter.

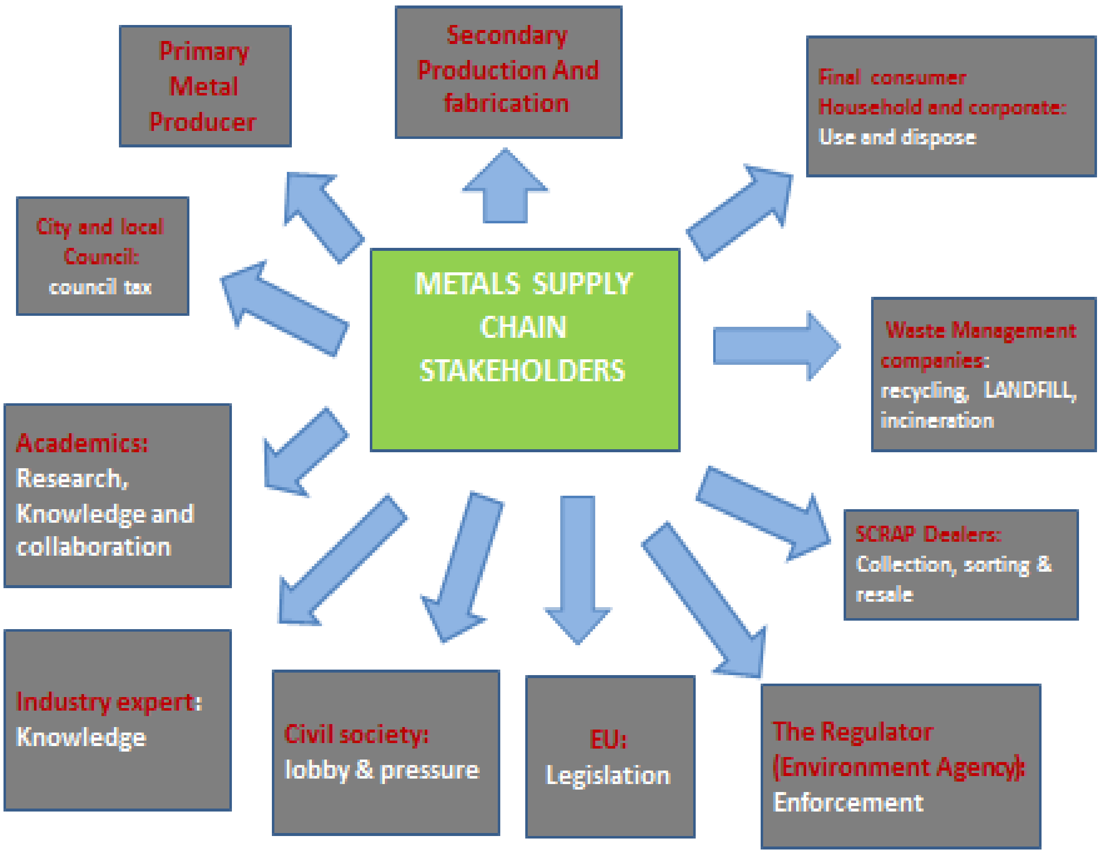

Figure 5.2: Metal supply chain map illustrating various stakeholders operating within it.

5.3 Stakeholders selected (interviewees)

In total, 15 stakeholders spanning different business sectors were interviewed based on personnel highlighted in Figure 5.2. Table 5.1 details the function of each subject, their role, and the business sector they were identified from. It is important to state here that in the analysis of the interview transcripts the words stakeholder, subject, participants and interviewee are used interchangeably.

Table 5.1: Characteristics of the stakeholders interviewed

	Position/Role	Stakeholder Type	Date	Interview ID	No of years of experience
1	Director	Scrap metal dealer	23/11/2016	SD	25
2	Waste Strategy Officer	City council	14/11/2016	LC	8
3	Senior lecturer	Academic	15/11/2016	AC	10
4	Post Industry-academic	Industry expert	16/02/2017	PIE	15
5	Strategic Waste Policy Manager	City council	05/04/17	LC2	7
6	Quality Manager	Metals producer	11/05/17	MP	14
7	Director	Metals fabricator		MF	18
8	Senior Research Fellow	Academic	14/06/17	AC2	15
9	Product Sustainability officer	Primary metal producer	25/05/17	PMP	15
10	Association Secretary	Household consumer	26/05/2017	HC	23
11	Environment Officer	Corporate consumer	25/05/17	CC	10
12	Chief campaigner	Civil society	22/05/2017	CS	20
13	Political party leader/Candidate	Policy maker	27/03/2017	PM	30
14	Director	Social enterprise	14/06/2017	SE	15
15	Group Leader	Civil society	09/06/2017	CS2	25

5.3.1 Set of interview questions

The questions posed to the selected stakeholders cover critical areas including the understanding and working knowledge of the circular economy paradigm, the perception of the subjects and experience regarding the implementation of circular economy principles in their respective fields. The interview was carried out by asking a variety of open-ended questions to obtain data from the stakeholders regarding drivers and barriers to circular economy and policy implications of a transition to circular economy. Examples of some of the questions asked include:

i. What is your take regarding the overall concept of circular economy (CE) and how do you think it constitute a competitive edge over the linear economy (LE)?

ii. In your opinion, why do you think the move towards the CE is slow despite all the advantages and competitive edge it offers in comparison with LE?

iii. If the transition from a linear economy (LE) to Circular economy (CE) is to become a success, what/who in your opinion will be responsible in taking the initiatives forward?

iv. What policy instruments do you think would be necessary for the drive towards Circular economy (CE)?

The full list of interview questions is presented in Appendix D

As highlighted in Chapter 3, section 3.6.3, an analytical procedure that allows for the natural emergence of themes, and with the ability to enrich findings from the stakeholder's interviews was adopted to analyse the ensuing qualitative data. This technique is known as thematic content analysis and has been adopted in a number of studies such as McGrath and Pistrang (2007), Fereday and Muir-Cochrane (2006), Pope et al. (2006), Burnard et al. (2008) and McMillan (2009). The technique offers useful insight whilst enhancing the identification of other important issues that were not initially thought of as part of the overall steps towards understanding the transition towards CE. In doing so, the outcomes would help put into perspective the results of the LCA case studies provided in chapter 4 whilst enabling a robust and viable understanding of the CE.

5.4 Data analysis of the stakeholder's interviews

Thematic-content analysis yielded nine main themes and several sub-categories, based on the responses by the stakeholders, shaping the understanding of the key factors driving the implementation of circular economy. The recurring themes identified include: understanding, opportunities, challenges, leadership, economic system, political system, stakeholder roles and policy options and are summarised in Table 5.2. The first column in the table shows the themes and sub-themes that emerged under each theme. The second column indicates the stakeholders that shared views under each theme and sub-theme using the stakeholder codes assigned to each from table 5.1. the frequency refers to the number of the stakeholders that shared views under each theme and sub-theme.

Table 5.2: Themes derived from the interview process

Themes/ dimensions/categories	Subjects that shared similar views	Frequency
1.Awareness		
(i) High	AC PIE AC2 PMP CS2	5
(ii) Medium	SD MP MF CC CS PM SE	7
(ii) Minimal	HC LC LC2	3
2.Leadership		
(i) Public	CC PM	3
(ii) Private		1
(iii) Both	MP AC2	3
3.Economic System		
(i) Neo liberal	SD LC AC PIE LC2 MP MF AC2 PMP HC CC CS PM SE CS2	3
(ii) Planned		2
(iii) New paradigm	CC AC2	2
4.Interaction		
(i)Minimal	MP	3
(ii)Fair	CC MP	3
(iii) None	LC LC2	2
5.Political system		
(i)Short term	SD LC AC PIE LC2 MP MF AC2 PMP HC CC CS PM SE CS2	7
(ii)Long term	PM	5
(iii) Brexit	SD LC AC PIE LC2 MP MF AC2 PMP HC CC CS PM SE CS2	9
6.Barriers		
(i) Planned obsolescence	SD LC AC PIE LC2 MP MF AC2 PMP HC CC CS PM SE CS2	10
(ii) CE Options	CC	
7.Drivers		
(i)Consumer demand/pressure	MP	1
8.Policy Options		
	SD LC AC PIE LC2 MP MF AC2 PMP HC CC CS PM SE CS2	13

In the next section, a discussion of the themes and the categories that emerged regarding the broad area of circular economy is presented.

5.4 Emerged themes regarding circular economy in the metals industry

In this section, the emerging themes and the categories are discussed. Each theme is illustrated by quotations from the stakeholders using the designations defined in Table 5.2.

5.4.1. Awareness

This theme refers to the overall knowledge and understanding of the concept of circular economy. It deals with the perception, views and overall level of awareness of the interviewees regarding the circular economy. During the course of the interviews, it became apparent that there are different levels of understanding and relevance of CE. All the interviewees demonstrated at least a minimal level of awareness of the CE concept. One interviewee stated that:

"Circular economy is one in which the production and consumption of resources are decoupled from economic growth by the control and efficient use of resources" (PIE)

Another said:

"CE is a recycling symbol, reduce, reuse and recycle" (SE)

Similarly, another respondent stated that:

"It is minimising the impact of our use of resources. It might not be taking a material right back to its origin but increasing the life and or reusability of that item or repurposing it to another purpose entirely. It is about decoupling economic growth from resource consumption" (MP)

The highest level of awareness was expectedly demonstrated by the academic and industry expert stakeholders as well as a primary metal producer. A primary metal producer has this to say regarding the concept of circular economy:

"It is about taking the materials we have and either reducing the amount of material we use or it could be about reusing remanufactured or recycled materials. It is kind of a waste hierarchy we start off at reduce, recycle, remanufacture and reuse. CE is about designing products that basically close the loop on material recycling or designing things that reduce the amount of materials needed or extending the life of a product. Fundamentally for me, it is about reducing the environmental footprint of a product by using those approaches" (PMP)

To further ascertain the level of understanding of the concept of circular economy, another key stakeholder expressed the following views:

"Any notion of CE is utopian really. In principle, the idea would be to mimic what ecosystems do in nature, which is to reuse and recycle material and resources as much as possible within the system rather than keep extracting from the surrounding environment and dumping the waste at the end of life. The idea is to find ways of different parts, economic sectors, industries to be linked in such a way so that the inputs of one sector are the output or leftover bits of another sector eventually closing the loop and keep using the materials over and over again as much as possible" (AC2)

The lowest level of awareness emanated from the households and the social enterprise who viewed CE interchangeably with terms such as recycling and sustainability. For instance, one subject likened sustainability to these terms as follows:

"CE is a recycling symbol, reduce, reuse and recycle" (SE)

This is further corroborated this by another subject put the meaning of CE in the following manner:

"It is basically about making sure that waste is reused and is put back in the economy…. It is ambiguous like the term sustainability" (CC)

The concept of CE also had an extended meaning to particular stakeholders. As one of the respondents pointed out:

"It is about extending the life of redundant products as well as reinvesting in the local economy. We are so involved in recycling side of business with local people we can see everything being reinvested in the local economy; we can see the local goods being donated by local businesses giving it a new lease of life, helping disadvantaged people" (SE)

From the different opinions and views expressed by different stakeholders based on their respective quotes, it is clear that the concept of circular economy is still very much ambiguous, although most stakeholders have a knowledge of what the concept really entails. At the moment, there is no globally acceptable definition of the circular economy and most practioners and stakeholders see the concept in different ways. A lack of holistic description detailing the meaning of circular economy within a well-established framework is one of the biggest problems inhibiting the embrace of the concept into mainstream decision making. This observation is in line the study by Geissdoerfer et al. (2017) who submitted that a lack of standard definition of the concept of circular is one of the key factors limiting its acceptance and implementation in environmental decision making. Until there exist a unified framework that is all encompassing, policy makers and other key stakeholders might not buy into the concept fully. One of the stakeholders summarized this imbroglio by drawing from his own personal experience when he said:

*"You see, this lack of standard definition of circular economy is really a big problem and its part of the reason why policy makers and funding bodies are not embracing it at the moment. I attended a seminar on circular economy some months back and at the end of the seminar, every participant came to the realisation that we do not fully understand what we are all talking about given the vast array of views expressed by every contributor to the subject of circular economy. It is therefore important that a unified and globally acceptable definition of the concept is put in place so that effective meaning of the concept can be derived." (*AC2*)*

Clearly, as highlighted in the above quotes as well as findings from the literature, for circular economy concept, with its many advantages, to see the light of the day and become integrated into mainstream business and policy decision making, there is the need for a globally acceptable standard definition.

5.4.2. Economic system

The economic system is a major theme that emanated from the interviews. The participants were asked about their thoughts on the economic system regarding CE. The discussion largely revolved around the neo-liberal economies sometimes also referred to as free-markets found in Europe and other western advanced countries versus planned economies such as that found in China, parts of Asia, the Middle East and Africa. In order to be able to put the responses of the participants into perspective it is important to explain key important concepts such as an economic system and free market economy.

An economic system is a collection and interconnection of organisations or institutions used by a nation to allocate and utilize its resources and therefore helps in providing answers to basic economic questions of what, how much, how and for whom to produce. Free market economy pertains to how resources are allocated by markets through the price mechanism. The laws of supply and demand dictates the production of goods and services. A pure free-market economy is mainly a theoretical concept. In practice, each country, even capitalist ones, places some form of restrictions on allocation of resources, ownership and exchange of goods and services. Minimum wages that are set by many governments around the world is an example. On the other hand, in a planned economy, all economic decisions are made by a central government. The government decides what to produce, how to produce goods and how to distribute goods and services within the economy. All these interrelated concepts plays a very big role towards the understanding and implementation of CE. For instance, a metal producer has this to say:

"The only way you can do it (i.e. circular economy) in a free market is probably through economic subsidy; making it commercially viable to do things likes co-location, cooperation between manufacturers that are ordinarily competitors and cooperation within the whole supply chain. I can see China can make decisions quickly. In the free-market it would be all about the incentives" (MP)

This is further supported by one subject who puts it succinctly:

"I think there is no better way of getting people to reuses and recycling than to incentivise. In lots of other countries throughout Europe and south East Asia, you have lots of different incentives encouraging people to recycle. You get money for bottles and plastics" (SE)

However, other interviewees raised concerns about the current economic system and its ability to fully capture the cost of economic activities on the environment. The subjects view the economic system as flawed when it comes to environmental concerns and expressed doubts about the achievability of circular economy under such a system. An interviewee stated:

"I keep talking about the economic model but the economic model is not conducive for circular economy and environmental sustainability. They are pulling in different ways. We will never achieve genuine environmental sustainability and development when this economic model is pushing us down this direction" (CC)

Another interviewee further added:

"The current economic system economic does not intrinsically put value on many ecosystem services seen as outside the market. This is a misguided view. Nothing is truly

independent of anything else…..because all these indirect chain of effects are artificially left out of conventional economic thought” (AC2)

There has to be a more open recognition of the fact that the current economic paradigm or mind-set fundamentally does not take into proper account any of the indirect side effects of economic activities in terms of loosely speaking environmental impacts. Economics as a discipline would do well to incorporate more and more biophysical elements into economic curriculum and academia, to training programmes for present and future economists so as to drive home this concept of circular economy. Essentially, for the concept of circular economy to become viable in terms of acceptance and implementation, it must be integrated in a consistent manner with the overall economic systems and its mode of operation within a free market economy must be well defined. For further details in terms of views from stakeholders, **see Appendix C.**

5.4.3 Political system

A political system here refers to the system of government and political structure upon which a country operates. In Europe, most of the countries have a democratic system consisting of at least two arms of government namely the legislature in the form of an assembly or parliament, and the executive headed by a chief executive known as prime Minister or president. Both arms of government are usually voted in for a fixed short term period, lasting five years in most instances. This short term nature of political office tenures is viewed by some subjects as a key factor affecting the implementation of the circular economy. They argued the need for long term policy to promote sustainability and circular economy goals and initiatives and cited the short term policies and political points scoring as factors inhibiting the overall embrace of circular economy. As indicated by a policy maker:

“We have had 35-40 years of neo-liberal politics that said greed is good and inequality doesn’t matter, we can keep trashing the planet. I believe that politics is coming to an end because it has failed…. it’s time to replace it with something new. A struggle for a CE, one that acknowledges damage created by products is part of that political change. We need to go in the right direction, not the wrong direction” (PM)

Another Subject also expresses a similar view:

“Political systems can be a barrier to CE but I think fundamentally it is the economic model. The politicians are still functioning with the capitalist economic model” (CC)

One way to overcome any problem associated with a particular political system as suggested by a policy maker is to look at similar systems and what they are doing right. This is illustrated in the quote below:

"We need to point at places where some of these things are already being achieved and say this is perfectly possible, there is nothing extra-ordinary or radical about this. There are parts of the world that are already doing this". (PM)

For further details in terms of views from stakeholders, **see Appendix C.**

Another political system worth considering especially in Europe is the membership to European Union EU. The EU is a political and economic union of 28 member states, with members sharing an internal single market, legislation and enjoying free movement of people, goods, services, and capital within the market. The word "Brexit" is derived from merging the words Britain and exit and is a shorthand way of referring to the UK leaving the EU. After such departure, EU directives won't apply anymore to the UK such as the EU package on CE discussed in chapter two. The results of the interviews indicated that the majority of stakeholders had a relatively negative feeling and experience towards Brexit. This result corresponds to HM Treasury's (2016) forecast that leaving the EU would hit the UK economy hard (HM Treasury, 2016). In the aftermath of the Brexit vote in June 2016, the pound tumbled to a three decade low against the dollar as a result of uncertainty over the long term prospects of the UK economy outside the EU (Van Reenen, 2016). The pound further fell in October due to further fears of a hard Brexit.

Figure 5.3: Sterling Markets (Source: Bank of England, 2017)

The pound is still down about 14% against the dollar and around 10% against the euro compared to the pre June 20016 referendum rates. It is however not all negative. The falling pound has meant falling wages and consumer spending power but also meaning that people have become more employable. Official figures from the Office for National Statistics (ONS) show the UK unemployment rate for May 2017 at 4.5%, its lowest since 1975 (ONS, 2017).

Figure 5.4: UK Unemployment Rate (Source: Office for National Statistics (ONS), 2017 Graphic: Mehreen Khan/FT)

The metals industry is no different from the rest of the UK economy in terms of the effect of Brexit. While UK exporters benefit from the depreciation in sterling, it also means the cost of imports has risen. This has an impact on multiple stakeholders within the metals industry especially specific metal producers who have a limited choice of raw material suppliers while scrap dealers can potentially export more. If the UK is to continue to trade with Europe, it will have to comply with EU directives on almost all products. However, the opportunity to have higher standards than Europe is also a possibility. The fact that the UK will no longer be bound by EU requirements could lead to more stringent domestic standards, provided the requirements do not put the UK metals industry at a disadvantage compared to their counterparts in the EU and beyond.

Furthermore, after Brexit the UK can use any measure to promote or pursue sustainability and environmental goals. An example of such measures or instruments is the concept of state aid. State aid is defined by the EU as "*an advantage in any form whatsoever conferred on a selective basis to undertakings by national public authorities*". It is a European level playing field concept in that no state can assist its businesses financially or otherwise to be more efficient, produce cheaper products so they get advantage in the market. For a measure to be deemed as state aid, it has to be intervention by the state or through the use of state resources, confer advantages to the recipient on a selective basis, distort competition and likely affect trade between member states. In the absence of EU laws and directives governing state aid, the UK might provide incentives to force markets to converge to CE objectives.

5.4.4 Leadership

This relates to the views of the participants on leadership in a transition towards a circular economy in the metals supply chain whether implicitly or explicitly. Various opinions were expressed as illustrated in the quotes below. The main leadership options that were mainly proposed were public, private and a mix of both. A policy maker stated:

"I think it's the policy makers that have to be the leaders, partly because industry even the best ones should be pushed to do better,….there has to be political leadership, setting a challenge" (PM)

This opinion is further echoed by another subject:

"It is got to be government, changing the status quo" (CC)

"In the aerospace industry, it is driven by the large OEM customers…..their focus is predominantly production and cost. In terms of CE, they are pushing for things like reduced tooling costs…" (MP)

An opposing view was offered by a different interviewee who submitted that:

"I think a bit of both public and private leadership is needed. I wouldn't want to promote too much government interference. A quango would be ideal as a go-between for government and private industry. From what I have seen lately of previous government

legislation, it is not entirely practical to implement and some cooperation between government and industry would be the most practical way to do that" (MP)

A quango as used by the subject above refers to a Quasi-Autonomous Non-Governmental Organisation. They are semi-autonomous entities that get funding from the government but operate independently of government interference or control. Examples of a quango in the UK are the Environment Agencies, the Forestry Commission and the British Council.

This viewed is supported by an academic who said:

"Both the public and private sector have a role to play. Governance and legislation have an important role to play on the other hand the private sector can also be proactive" (AC2)

The private sector can be proactive in ways that appeal to the public such as active advertising of a product that is greener in terms of being making use of recycled components and materials and being more in line with the CE concept. In addition, there is an unwillingness of companies to take on leadership within the metals supply chain and bring about change unless there are visible economic benefits or their competitors are making the changes as well. This unwillingness affects the adoption of circular economy initiatives by smaller firms in the supply chain.

5.4.5 Interaction

Interaction here refers to how individual stakeholders engage one another for the purpose of achieving better outcomes. Understanding stakeholders allows each stakeholder to consider issues such as expectations, existing relationships, capacity to engage and influence. This theme therefore captures the interaction between the various stakeholder types within the metals supply chain. Stakeholder interaction appeared to be higher between stakeholders in the same line of business as supported by the statement below expressed by a metal producer regarding the interaction between competitors and the city council:

"*There is a fair bit of interaction. We are integrators for big companies which means that we are responsible for buying cutting tools for them so we supply with our own tools as well as buying our competitors tools that we don't make or don't want to make. There is a lot of interaction in that respect……" (MP)*

Based on the above quotes, it can be observed that stakeholder interaction appeared to be less especially between key stakeholders whose area of operation are far from each other. For instance, a subject commented on lack of interaction between stakeholders and how it can affect cooperation towards implementing a new concept such as the circular economy. This is supported by the statement below:

"We don't deal much with the local council. We tend to avoid them" (MP)

Another subjected commented:

"I don't think we buy from such small players, we deal with big scrap dealers like ERM, Maybe the big dealers interact with the smaller dealers" (PMP)

Drawing inference from the above statements clearly suggest that there is little interaction between key stakeholders in different stage of the supply chain of metals. For example, there is not much interaction between the large metal producers and the local scrap dealers. The big companies instead deal with big scrap dealers who may deal with the smaller companies below the supply chain. This lack of interaction between stakeholders even within the same business market is a key contributor to the lack of acceptance and implementation of circular economy within the sector.

5.4.6 Planned obsolescence

Another recurring theme is planned obsolescence which can be described as a business strategy in which the lifespan of a product or service is planned and built into it from its conception, thereby driving the consumers to purchase new replacement products and services in the near future. More simply put, planned obsolescence is a deliberate way of shortening the lifespan of a product. Planned obsolescence as a theme was constantly recurring during the interviews because of the focus of the study on metals which form large components of consumer goods and have generally short lifespans. A number of the stakeholders have demonstrated disproval of the concept of planned obsolescence. For instance, a corporate consumer of metal products:

"In this economic model (i.e. the current economic dispensation) we need to sell stuff to make money, people could still have jobs and an economy that works if people fix things. It doesn't have to be about making things and throwing things away" (CC)

In the same vein, a policy maker echoed these thoughts saying:

"An important part of the CE is an end to planned obsolescence. When I was a child, I remember people had fridges that had lasted 40-50 years. We obviously can make fridges that last years. Why aren't we? That's the problem of planned obsolescence. We also need to make sure for example sticking with fridges that as many components as possible are reused without having to go through any recycling process that invariably requires additional energy. So part of a CE should be standardised parts. That you can simply reuse rather than reprocess" (PM)

However, another respondent had a slightly differing view of planned obsolescence with respect to technology-based goods such as televisions, mobile phones and game consoles. When it comes to different technology, there is the occurrence of" circumstantial obsolescence" that occurs over time and is good for the society. Examples include new Boeing and Airbus passenger aircrafts that are faster, lighter, and safer and consume less fuel rendering them more environmental friendly. Other examples include hospital equipment such as MRI scanners that have quickly replaced old x-ray machines and brought about advancements in healthcare. Against this backdrop, the interviewee said:

"I am not a fan of Planned obsolescence. The thing about technology is something else termed "circumstantial obsolescence". As technology improves, things get faster. Do you want to be the one left behind? It is about inclusion and exclusion. Technology moves on. The people that don't catch up are excluded. They can't play the latest video games. They can't see the latest movies on the VR headset" (SE)

The views expressed by both subjects above provides a uniquely useful insight into one of the key issues inhibiting the adoption of the principles of circular economy. As indicated, both views are valid in a way but finding a way to understand the point of view of both subject can go a long way in addressing some of the challenges of implementing circular economy. Both views constitute a conundrum but finding a way to balance both is important if a clear vision about the adoption of circular is to emerge given that it pose the problem of a choice between longevity and durability on the one hand and employment opportunities, quality of life and wellbeing as well as advancement on the other hand.

5.4.7 Obstacles (Challenges)

The move to a circular economy in the metals industry is not without its obstacles and was a theme that came up with almost all the participants especially the producers as they have to deal with the transition first hand. The main obstacles are discussed as sub-themes in the succeeding paragraphs.

(i) Skills

Skills as used here refers to the ability to carry out certain tasks well. In order to carry out a particular task, one needs the appropriate skill set. This skill set is usually gained through training, knowledge and practice. In the case of the metal industry, for a move away from linear production to a more circular one to become viable, certain knowledge and skills are required. A respondent echoed this view when he submitted that:

"In our industry, being able to regrind tools effectively requires additional skill and technical knowledge to be able to design the tools with regrinding in mind, to produce the tool reputably so that a regrind would function exactly like a brand new tool would" (MP)

This is further echoed by another interviewee who pointed out:

"I think it is technical. Achieving the right grade of purity in the recycled metals so they can be used in the same application maybe a challenge" (AC2)

(ii) Availability of circular economy options

The lack of suitable CE options emerged as a main obstacle during the course of the interviews with the various stakeholders in the metals industry. CE options were either non-existent or limited, thereby not offering much choice. As one of the respondents pointed out:

"We only have 3 main suppliers and they are the only suppliers of the raw materials so we are restricted in where we can get it from" (MP)

This is further supported by another subject who puts it neatly:

"I know all these possibilities but struggle to find a viable or option that isn't massively expensive…. an option that does actually deliver an environment benefit instead of jumping on the bandwagon…. but the opportunities are so few and far between" (CC)

These thoughts are echoed by another interviewee who submitted that:

"There are only two steel mills operating in the UK so we can only sell to two customers" (SD)

The CE options were found not to be economically viable and at times not environmental viable because the option are not locally available and transportation over long distances is required for delivery of goods. It is therefore very important to not only have CE options available but also have them locally, thereby reducing transport costs and emissions.

(iii) Data issues

A lot of metal that is recycled is sourced from electric and electronic waste (WEEE) from appliances such as mobile phones, laptop and desktop computers, printers, fridge's etc. The lack of understanding of data and how data storage works proved to be a huge stumbling block to WEEE recycling stakeholders in the metals supply chain. The challenge is in letting people know what data is, how it is stored, destroyed, how easy it is to destroy data and the protection and protocols in place to prevent anyone getting their hands on the data. For instance, a Subject corroborated this by saying:

"The biggest challenge is Data issues. People don't understand data…. When people donate laptops to us, some feel that that laptop will always have their information on it. They don't understand that the data is stored on a little flat metal disc or SSD and separating it from the main body of the laptop is relatively easy." (SE)

(iv) Production mix, raw material availability and affordability

Certain products are best produced via the linear production route. This is the case with certain steel products. This may be due to price or raw material availability. A primary metal producer PMP stated that:

"It's a number of factors, its economics, it may also be due a product mix; certain products lend themselves to being manufactured by the linear rather than a circular route, it is also worth noting that the electric arc furnace (EAF) use other materials other than scrap. Some EAF can run on primary material as well, it doesn't mean it is always scrap. An EAF uses a batch process, while a blast furnace (BF) is a continuous process and there are much more economic investments in a BF and you run it for a longer period and as such you

are committed for a certain number of years (e.g. 10-15 years). The EAF is shorter term. So once you make that initial investment, you are left with what you have, locked in" (PMP)

5.4.8 Policy options

This pertains to more engagement of the policy makers with the view to gain further understanding of the circular economy. The use of policy instruments such as the replacement of VAT with damage taxes can encourage the transition towards a circular economy. The carrot and stick approach always works. On one hand more stringent regulation and on the other more widespread incentives, economic incentives. In tandem, these two would be effective but they are not the only ones.

5.5 Summary of key findings

Based on the overall analysis of the interviews conducted, a summary of some of the more specific findings is provided in this section as follows:

- The concept of circular economy is understood by most stakeholders, despite its lack of a standard definition and is sometimes used interchangeably with the term "sustainability". Given this level of general awareness, the transition towards a circular economy might become easier given that little effort will be required in terms of encouraging stakeholders to adopt it.
- A certain level of interaction occurs between some stakeholders while others have no interaction at all. This lack of interaction between key stakeholders is a major obstacle in the quest towards adopting the circular economy paradigm within environmental decision making.
- There exist different degrees of power among the stakeholders with the dominant ones being the consumer, the large producers and the policy makers. The local council are very low on the power scale and are constrained economically. Most of the policy lies with the Environment Agency that regulates the industry with little or no local council input.
- There are a limited number of CE options available to companies that might want to pursue them, especially local options. In other instances, the options are very impractical and may offer only material recovery gains but not much emissions reduction due to the need to transport across long distances.
- The current economic system has been identified as a major stumbling block by the interviewees to the transition to a CE. There is therefore the need to

- Short term policy and political goals and gains do not aid in long term policy making that would promote CE and sustainability.
- Consumer behaviour and consumerism drives both the current linear model and as well the move to CE. Consumer demand encourages the concept of planned obsolescence leading to more production and waste. Similarly, consumer demand and pressure pushes multiple stakeholders to revaluate their supply chain and consider sustainable alternatives.
- The waste collectors and scrap dealers have a dual agency role that goes unnoticed. They serve as the last point or node on the forward supply chain collecting and sorting the waste thereby adding value to it as well as the beginning or first node on the reverse supply chain supplying the cleaned and sorted waste back to primary producers for reuse and remanufacturing. They bring together the various stakeholders on the different ends. This role is greatly underappreciated.
- The small and medium scale scrap dealers operate in almost a perfect competition setting with all of them being price takers. No one of them can determine price. The market is in a way self-regulatory.

5.6 Discussion

In this section, a general discussion based on the views expressed by the key stakeholders interviewed is provided under different dimension as presented below

5.6.1 Stakeholder tension

From the “interaction theme” outlined above it can be observed that there exist some levels of tension between certain stakeholders. For instance the civil society promoting climate change and sustainability has no direct dealings with the local enterprise partnership that comprises of all the big businesses within the region and where most important economic decisions are made. Similarly, the local councils have no power besides the collection of council taxes and little to no involvement in the regulation of businesses in the metals industry. The responsibility lies solely with the Environment Agency which enforces all domestic and EU regulations pertaining to the environment, waste and circular economy. This tension hinders possible collaboration between the different stakeholders.

5.6.2 Reductionist view of circular economy in Europe

From the interviews, the participants expressed mixed reactions about the European approach to circular economy in the metals industry. Majority of interviewees felt that the

European approach to circular economy in the metals industry is rather limited. In Europe, there is a great deal of focus on waste recycling but not enough rethinking of how the economy works and how to link different industry sectors so as to effectively make use of the by-products and waste flows in a more efficient way. It is easier to set waste recycling targets than to find ways to link different independent sectors to link to one another, to work together, collaboratively towards a common goal.

5.6.3 Economic paradigm shift

The interviews questionnaire survey revealed that a vast majority of stakeholders supported the idea of an economic paradigm shift, arguing for a more open recognition of the fact that the current economic paradigm or mind-set fundamentally does not take into proper account any of the indirect side effects of economic activities in terms of environmental impacts which is in line with findings by Ghisellini et al. (2015). Economics as a discipline would do well to incorporate more and more biophysical elements into economic curriculum and academia, to training programmes for present and future economists so as to drive home this concept of CE. Looking at the world from a purely economic perspective misses a lot of important aspects of circular economy. One cannot just wait for things to become cheap enough to do them. Sometimes, there is the need to be proactive. To do this, it is important to merge views that differ in a way so as to allow for the incorporation of these non-monetised effects into the economy. For instance, the policy makers should put in place a robust structure such that a given product could be made to be made to be accountable for the indirect damage it causes on the environment. In doing so, it will encourage manufacturers of such products to factor in circular economy concepts into their overall supply chain.

The idea of a paradigm shift brings about fear of a loss of livelihoods built on the current economic model and the fear of the unknown. There might be disruptions in the very short term but ultimately in the long run, such events will even out naturally because if the current economic approach and way of thinking continues to neglect these indirect effects, the bill will get much steeper and it will get to the point where fixing all the damage cannot be afforded. Time is running out of in terms of incorporating these externalities into the economy. Not incorporating these externalities will eventually come back to bite leading to questions such as: what is the economic cost of remediating the damage? What is the economic cost of mitigating the effects of climate change? It is going to be huge? That will affect the livelihoods of more people much more than some additional cost imposed by a more inclusive economic paradigm. It is a matter of short term benefits vs long term benefits and more often than not policy makers, the economists and those responsible tend to be more focused on short term benefits. It is about time to rethink our economic paradigm. Circular economy should be the natural outcome of this rethink. Overall circular economy offers a great deal of advantages however, as reported by Genovese, Acquaye et al. (2017) the economic viability of the circular supply chains may be questionable, as mechanisms to endorse them maybe very weak.

5.7 Critical reflection and recommendations Overview and context

5.7.1 Overview and context

The linear approach to the consumption of natural resources resource, based on the "take-make-use-dispose" pattern, does not seem to be sustainable given its potential to deplete resources whilst polluting the environment (Andersen, 2007; Genovese et al., 2017; Murray et al., 2017). This is put into context by Hoornweg and Bhada-Tata (2012) who submitted that cities of the world are generating roughly 1.3 billion tonnes of solid waste per year and that by 2025 such waste might gallop to 2.2 billion tonnes, resulting in a yearly cost of $205.4 billion at current rate, with a corresponding rate of $375.5 billion by 2025. To address these environmental and economic challenges with the view to improve the productivity and efficiency of resources, the concept of a circular economy has been developed (Ellen MacArthur Foundation, 2013; European Commission, 2015; Bakker et al., 2014b; Bocken et al., 2016). It is a strategy to facilitate economic growth and at the same time minimise resource use by closing all resource loops and reconnecting them at various nodes, thus reducing and ultimately eliminating waste (McKinsey & Company 2013). Adopting a circular economy generally seeks to reconcile the establishment of commercial value with the adoption of resource efficiency strategies including recycling, reuse, repair and remanufacturing by leveraging the economic and environmental value embodied in products (Bakker et al., 2014a; Bocken et al., 2016).

In their report Becque, et al. (2016) submitted that the concept of circular economy is based on three key ideologies namely "(a) to preserve and enhance natural capital by controlling finite stocks and balancing renewable resource flows; (b) to optimize resource yields by circulating products, components, and materials at the highest utility at all times; and (c) to foster system effectiveness by designing out negative externalities. Against the backdrop of these ideologies, it is apparent that leaning towards a circular economy offers an enormous potential towards the reduction of carbon emissions. However, despite the increasing adoption of the concept, it is lacking in terms of a generally acceptable definition, as such no common understanding of the concept has been established. Consequently, this has led to many vital questions in this emerging field of CE to remain unanswered.

In an attempt to provide answers to some of the unanswered questions, the current work, using a mixed-mode research approach explores the drivers, barriers and policy implications of circular economy from the perspective of the metal industry. The first approach entails an exhaustive examination of the supply chain of representative metals that have primary and secondary routes of production through using environmental lifecycle assessment framework. Four case studies were considered to demonstrate the competitive edge of the circular economy paradigm over the linear approach, at least from a purely environmental perspective. Different stakeholders have very different views and perceptions of the concept of CE as well as diverse expectations for its implementation. Set against a background of stakeholder engagement, key stakeholders from the metals supply chains were identified (including scrap dealers, public authorities, consumers, manufacturers, recyclers, civil society) and interviewed with the view to provide qualitative empirical evidence of the feasibility of such transition. Thematic content analysis of the interviews with key actors and stakeholders yielded seven themes and several sub-themes which can shape the understanding and facilitate the transitioning from a linear economy to circular economy, whilst laying a solid foundation for its acceptance and future implementation.

As with other studies in this evolving field, it was established that the move towards a circular economy offers a number of benefits ranging across resource availability benefits through improvements in resource scarcity and reduction in import dependency; ecological benefits through the avoidance of waste, improvement to eco-design and reuse; economic benefits through the provision of opportunities for economic growth and innovation; and social benefits by encouraging consumer behaviour that is sustainable and generating numerous employment opportunities.

5.7.2 Pertinent issues surrounding the implementation of CE

However, it is absolutely clear that are other issues and challenges of embracing CE. For instance, most of the aforementioned benefits are based on the premise that the loss of material residuals measured in physical units will be minimised but this perception gives rise to a key important question: how far can the society go in efforts geared towards recycling of materials? Although recycling offers a great deal of benefits, however as soon as recycling routes are explored subsequent benefits becomes more difficult to actualise. It must therefore be recognised that at some point in time there is bound to be a cut-off point where recycling may become too cumbersome to yield the desired benefits. As such, a CE cannot promote recycling forever. As established earlier, the move towards a CE offers very clear environmental benefits when viewed from a material reuse and recycling perspective, however in a market economy the cost of natural resources and materials may become too low and will largely show the costs attributed to mining and short-term values but not with resource depletion or environmental cost. In this instance, only a few range of CE options will make practical sense at least from the perspective of company managers. In a purely capitalist setting, most CE options will only be undertaken only when it is desirable from an economic point of view (Andersen, 2007). It is therefore pertinent to analyse CE options more carefully from a socio-economic perspective regarding how such options can yield an overall net benefits.

Circular patterns are not easy to implement in all sectors. For example, some solvents and chemicals are very volatile and become airborne after use. More than that, energy is degraded and used up after use and becomes no longer usable to do work and cannot be recycled. Of course, CO_2 released by fossil fuels consumption can be taken up via photosynthesis, but the time scale of these processes is much longer than the time scale of the economic processes. This means that a prerequisite for circular economy to be effective is to increase energy efficiency, plan decrease fossil sources and increase renewable patterns in support to production and recycling processes.

5.7.3 Winners (supporters) vs losers (opposition)

The transition towards a CE entails a paradigm shift away from the current linear approach but it is very likely that such a transition will be contentious. The implementation of circular economy patterns will displace a number of activities (e.g. mining, old refining technologies, some linear processes, some disposal practices) whilst shrinking employment opportunities. At the same time new opportunities will be created for people and investors with appropriate skills in many sectors of the economy. This is likely to create conflicts among different stakeholders leading to the notion of “losers” (i.e. oppositions to a transition towards a CE) versus “winners” (i.e. supporters of the transition towards a CE). Examples of “losers” as identified by Becque, et al. (2016) include: primary sectors whose mainstream activities revolves around non-renewable material extraction, refining and transactions such as fossil fuels or minerals; manufacturers who focus on low durability whilst taking rapid obsolescence approach into their designs; waste collectors and disposal workers expecting a decrease in volume of waste and associated revenue; vendors or manufacturers of items or services that shares direct or indirect competition with products, business models or services that are aligned to the circular economy principles; manufacturers of products fast technological cycles targeted at acquainting consumers to upgrade regularly.

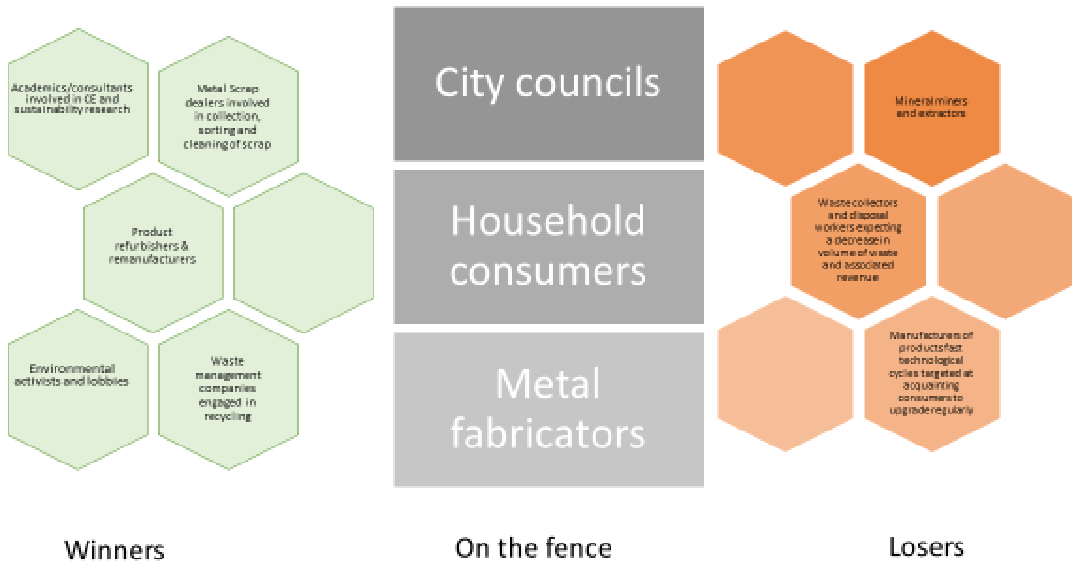

Figure 5.5: Winners and losers in the transition to CE. Adapted from (Becque, et al. 2016)

To counter the probable oppositions to a CE, a number of interests may passively or actively support the notion of CE and examples of such interests group include: manufacturers and vendors of products and services who put material and energy resources into efficient use given the large components of their renewable resources; developers of technical know-how whose business designs requires enhanced efficiency, renewability and improved durability; construction sector parties who are able to identify potential opportunities in providing circular services and products; providers of intelligent design, repair and maintenance services for products that designed to be durable such that they can be retained easily as the end-of-life of such products approaches; product remanufacturers and recyclers; provider of take-back infrastructure; businesses that are able to identify potential opportunities of CE with the view to hedge and preserve resource whilst safeguarding against resource access risks and volatilities associated with prices of products;

businesses whose modes of operation is in tune with performance and sharing economy; businesses who believe in CE as an avenue to tap into new customer segments and markets; environmental and climate change enthusiast and advocates and many more (Becque et al., 2016).

5.7.4 Recommendations and initiatives

In light of the above considerations, it is evident that in order to aid the effective implementation of strategies that are in tune with the concept of circular economy, necessary policy instruments and frameworks that extend far beyond currently available legislations must be in place. Legislations that encourage improved and better product design which avoids waste must be implemented. This is because better designs enhance the longevity of product, allows for easy repairs or upgrade whilst saving valuable resources. To achieve this, policy instruments must encompass Eco design directives whose main goal will be to improve the efficiency and ecological performance of newly developed products. This can be carried out by a way of establishing an obligatory product design and labelling standards. A number of companies are already thinking ahead. For instance, Dell, the computer giant, is already manufacturing new products from plastics recovered from obsolete computer products. Similarly, Michelin offers fleet customers to lease tires as against purchasing them outright thereby selling tires as a form of service.

Given the diverse interests highlighted earlier, it is very clear that the circular economy requires a clear regulatory framework with new mix of instruments. Policy makers responsible for public policy making must transcend the narrow perspectives attributed to CE and construct mechanisms that ensure that recycling and reuse takes place where it is socially desirable and efficient. This will require a careful analysis of the socio-economic perspective regarding how circular economy principles can provide net benefits. New legislation that brings together key stakeholders with the view to set ambitious agenda towards the CE must be established.

To ease the move towards a CE, Becque et al., (2016) six key policy areas to focus on including (a) public procurement policy; (b)establishment of collaborative platforms such as public- private partnerships with businesses at all levels including national, regional and city; encouraging value-chain and multiple sectoral initiatives and information sharing; investment in research and development especially in the field of materials science; (c) provision of technical support such as advice, training and demonstration of best practices for businesses as well as and financial support to businesses including incentive programs, direct subsidies and financial guarantees (d) fiscal policy such as VAT or excise tax reduction for products and services that emanates from the principles of CE as well as tax shift from labour to resources; (e) education, information and awareness such as the inclusion of CE and life cycle systems thinking into educational curriculum as well as through communication and information awareness campaigns; (f) regulatory frameworks including strategies and approaches for resource productivity; product regulations and extended warranties waste regulations which encompasses collection and treatment standards and targets, extended producer responsibility.

The evolving field of CE is a complex one given all the issues identified within the literature and based on findings from the current work. As such, there is no silver bullet towards realising an effective pathway towards the realisation and implementation of the circular economy strategies.

5.8 Chapter summary

The chapter presents detailed analysis and discussion of the interviews conducted with key stakeholders regarding the move towards a circular economy. Getting access to the stakeholders was quite challenging but unrelenting efforts led to 15 stakeholders being interviewed. Most of the Subjects are familiar with the concept of circular economy, so the views expressed by each of them are adjudged satisfactory. Overall, seven themes and several categories emerged from the stakeholder interviews providing deeper insights into the problems associated with the move towards a circular economy. Critical reflection is provided.

In the chapter that follows, a summary of the key findings, contributions to knowledge which emanated from this research is presented. Limitations and future work is also discussed.

Chapter 6: Conclusion and future work

6.1 Introduction

An overview of the key findings emerging from this work and how they have they have contributed towards meeting the research aims and objectives are provided in this chapter. The original contributions to knowledge and practice are also summarised, and lastly the limitations of the research and recommendations for areas of further study are presented. In order to put the chapter into perspective, it is important to re-state the overall aim of the research with the view to describe how the ensuing objectives were realised. To reiterate, the central aim of this study is *to investigate the environmental implications of circular production systems across a number of sustainability metrics in comparison to the traditional linear production paradigm using key representative metals as case studies, with the view to identify the drivers, barriers, market dynamics and policy implications of the transition towards a circular economy.* Against this backdrop, the overall aim could be comfortably said to have been achieved due to a number of research activities carried as described in the subsections that follows.

6.1.1 Initial review of key concepts in circular economy and knowledge gap identification

In chapter two, a detailed review of the concept of circular economy to identify the drivers, barriers and policy implications, in terms of the challenges they constitute towards the implementation of circular production systems, whilst identifying the gap in knowledge which the current work seeks to fill was presented. The review presented delved into the concept of circular economy and its associated challenges and lays the foundation upon which the overall thesis rests.

6.1.2 Development of a methodological framework to bridge the gap in knowledge identified

In chapter three, a detailed description of the overall methodological framework which was used to realise the aims and objectives was presented. Also included in chapter three was the research philosophy and paradigm which was adopted to guide the current research. The principles of LCA as a computational tool for exploring the environmental viability of the CE paradigm were presented. In order to seek the views and perceptions of key stakeholders within the metal sector a robust methodological framework based on qualitative analysis was adopted. The framework led to the application of thematic content analysis which led to the emergence of themes identified as key drivers and barriers towards the implementation of the CE.

6.1.3 Comparative analysis of linear vs. circular economy: a case study of metals sector

In chapter four, through the lens of environmental lifecycle assessment framework, across a number of sustainability metrics, the competitive edge which the circular economy paradigm offers in comparison to linear economy, using the supply chain of some selected metals that have well-established primary and secondary production routes as case studies, was demonstrated. Four key representative metals namely lead, copper, nickel and steel were considered, and based on the theoretical underpinnings of process LCA, the move towards a circular economy was demonstrated to offer a number of benefits in comparison to linear economy model. The comparison of the primary and secondary production highlights the benefit linked to the recycling of metals and the implementation of circular economy strategies, gaining an understanding of additional dynamics and implications that could arise by the implementation of the different production systems. Overall, the comparative analysis performed provided an in-depth understanding of the environmental impacts associated with the linear and circular supply chains.

6.1.4 Stakeholder views and perception on circular economy leading to emerged themes

Building upon the LCA study presented in chapter four and, after having proven the environmental soundness of the "circular" routes, the research then sought to look at barriers and drivers towards circular economy practices implementation. Set against a background of stakeholder theory, key stakeholders from the metals supply chains were identified (including scrap dealers, public authorities, consumers, manufacturers, recyclers, civil society) and interviewed with the aim to interpret findings through some well-established qualitative frameworks. In order to gain an understanding of the concept of circular economy from the perspectives of the stakeholders as to why the acceptance and implementation of the concept is slow, a detailed analysis of the interviews conducted was presented in chapter five. The analysis provided in chapter five is to explore the reason the adoption of circular economy principles is difficult despite the inherent advantages it offers. The analysis presented also provides useful insights into the understanding of challenges facing the implementation of circular economy.

A number of themes or dimensions which helps to shape the understanding of the challenges of transitioning from a linear economy to circular economy through thematic content analysis of interviews with key actors and stakeholders were generated. The themes generated include awareness, political systems, economic systems, leadership, interaction, planned obsolescence and other challenges and assists in establishing a robust qualitative empirical evidence of the feasibility of such transition. Based on the analysis and discussion presented in chapter five, it was observed although the transitioning towards a circular economy offers a great deal of advantages however, the economic viability of such transition may be questionable given that mechanisms to endorse them are deemed weak at the moment. For a move to circular economy to become a reality, concerted effort from all stakeholders including policy makers, energy professionals and the society at large is required.

6.2 Original contributions

Increasing GHG emissions, intensive global competition and a ballooning population utilising limited natural resource base constitute some of the challenges facing mankind in the 21st century. This is particularly the case given the overall increase in the level of material extraction towards meeting the needs of humanity. As the population of the world increases in number and wealth, the environmental burden of our actions through material extraction and utilisation is bound to increase. Concerns over these issues are no longer confined to the isolated environmental activist or advocates of green consumption. Government, industries, companies as well as financial markets are all rethinking their approaches to industrial activity by taking into consideration the entire life cycle environmental impact. The move towards a circular economy has been recognised as a potential solution to this resource challenges given the multitude of advantages it offers as demonstrated in this thesis. However, despite the glaring competitive edge of the circular economy approach, a lack of understanding of the concept is rendering its acceptance and implementation a difficult proposition. At present, relevant stakeholders are scrambling for an efficient, consistent and reliable approach towards understanding the concept for onward implementation. In pursuit of a system of operation that satisfies the dual role of GHG mitigation and wealth generation, the current research present a rigorous analysis of the circular economy based on quantitative (i.e. life cycle assessment framework) and qualitative (i.e. stakeholder engagement) approaches. In doing so, the current work contributes to knowledge and practice in the following manner:

- Consideration and demonstration of the LCA model beyond a single metric based on carbon dioxide emission in the form of global warming potential (GWP) by incorporating additional sustainability metrics including materials usage, land use, eutrophication, acidification and toxicology, to compare the linear economy approach with the circular economy. This is an important contribution given the increasing significance of multiple metric LCA analysis which ensures supply chain visibility and allows for thorough trade off analysis between the two approaches to be explored.

- Provision of unique insight into the understanding of the drivers, barriers and policy implications of the circular economy paradigm through stakeholder engagement within the metal and fabricated metal sector. The insights provided can be used to establish policy initiatives and identify business and consumer triggers, informed by qualitative empirical evidence, with the view to laying a robust foundation for the implementation of circular economy.

Table 6.1 below reports a synthetic description of research questions and related outcomes.

Table 6.1: Research outcomes

Research Question	**Outcomes**
What are the environmental implications of circular production systems, across a number of sustainability metrics, of selected metals that have well-established primary and secondary production routes, within the metal and fabricated metal sector in comparison to a traditional linear production model?	Through the lens of environmental lifecycle assessment framework, and based on the theoretical underpinnings of process LCA, across a number of sustainability metrics, using the supply chain of four key representative metals namely lead, copper, nickel and steel that have well-established primary and secondary production routes as case studies, the competitive edge which the circular economy paradigm offers in comparison to linear economy, was demonstrated and highlighted (See chapter Four, pages 67, 82, 97,111 & 120)
What are the drivers, barriers and main policy implications limiting the adoption	Set against a background of stakeholder theory, key stakeholders from the metals

of circular economy approaches, with a focus on the metals industry?	supply chains were identified (including scrap dealers, public authorities, consumers, manufacturers, recyclers, civil society) and interviewed. It was observed although the transitioning towards a circular economy offers a great deal of advantages however, the economic viability of such transition may be questionable given that mechanisms to endorse them are deemed weak at the moment. For a move to circular economy to become a reality, concerted effort from all stakeholders (see Chapter five, pages 144-146).
How can findings from quantitative study (i.e. assessment of the environmental implications of circular production systems vs. linear production systems) be integrated with findings from qualitative study (i.e. the use of interviews to gain in-depth understanding of the drivers, barriers and stakeholder views), with the view to gain a better understanding of the transition towards a circular economy whilst laying a solid foundation for its acceptance and implementation?	The pertinent issues with respect to CE in the metals industry include the fact that circular patterns are not easy to implement in all sectors, it should be recognised that at some point in time there is bound to be a cut-off point where recycling may become too cumbersome to yield the desired benefits and there will be winners and losers in the transition to CE (See Chapter 5, page 146-151)

6.3 Limitations of the current work and future research

Despite the mixed-mode approach (i.e. the integration of quantitative and qualitative methods) taken to investigate the drivers, barriers and policy implications of circular economy, there are a number of limitations associated with the overall methods and research output which are highlighted in the succeeding paragraphs.

6.3.1 Data sources

The reliance on secondary data for the undertaking of the process LCA work is one of the key limitations of the quantitative aspects of the current work. Although the Ecoinvent database used is robust and well established in that it is utilised by practitioners of LCA methodology worldwide, the use of primary data supplied by companies or industries based on, product and or process specific data may give a more detailed picture of the comparison between the linear and circular economy. Accordingly, as part of a future work, collaborations with companies or organisations who have genuine interests in circular economy should be established. In doing so, it is anticipated that primary data based on specific case studies can be obtained for detailed analysis to highlight the competitive edge of circular economy over linear economy.

6.3.2 Life cycle assessment methodology

Another limitation in this study lies with the fact that the comparative analysis between linear and circular economy was carried out using process-based LCA methodology which offers some level of specificity to the analysis. However, the specificity of the process-based LCA could be augmented with the systems boundary completion which the environmental input-output (EIO) LCA offers, to yield a well-established technique known as integrated hybrid LCA (HLCA), where specific (primary) data on each metal's supply chain are integrated with data from input-output model. By using the technique of HLCA, the visibility of the supply chain of the metals within a circular economy paradigm can be enhanced. In particular, the consideration of waste collection and transport is crucial when discussing circular economy. This is because if waste materials are too scattered and displaced, their concentration to be re-used as scraps may become too expensive in terms of resource investment and emissions. Process data on waste management and transportation are difficult to come by but such limitations can be accounted by utilising the technique of integrated hybrid LCA. This is important given that LCAs of circular patterns should include waste material collection and concentrations as a "new-mining", requiring different technologies and skills. This can help in highlighting in greater details the advantages of circular economy over linear economy. Conducting the LCA study within a hybrid LCA framework using primary data can help increase supply chain visibility and shed more light on the transition towards a circular economy.

6.3.3 Normalisation factors and aggregation

In this work, a considerable amount of the LCA work presented are compared within impact categories (e.g. CO_2 emissions in linear versus circular patterns), where units are the same, but they are not compared across aggregate categories. Aggregate comparison among categories is only performed through Eco-indicators 99, where end-point impacts are compared, instead of applying CML or ReCiPe normalization factors. However, normalisation factors of Eco-indicators 99 are not updated especially as it pertains to some aspects such as land occupation or water demand that are crucial in several cases.

6.3.4 Linear versus network-oriented circularity

In this work as with other studies that seeks to highlight the advantages of CE through the use of LCA techniques, it is well-established that extraction, beneficiation, refining, use and recycling, not to talk of the needed input flows other than the main feedstock, may occur in different and far away countries or regions. Such impact attributed to geographical boundaries are also well documented in the Ecoinvent database. The circular option which was investigated in this research was based on returning the scraps to the melting process (which still exhibits a linear feedback process), which is only one of the many possible patterns. As highlighted in section 6.4.2, the integration of waste materials and residues in other processes in the same area would show a different kind of circularity, aimed at creating local networks for circular economy. Against this backdrop, the use of a robust LCA framework which can capture the influence of waste disposals should be used as part of a future work.

6.3.5 Limited scope of sustainability indicators to cover circular economy

The sustainability indicators adopted for the LCA aspect of this work are limited in scope in that they do not capture some important indicators (e.g. social considerations) that could be used to shape the understanding of the concept of circular economy beyond environmental issues alone. Accordingly, the use of LCA-specific indicators may not be a sufficient strategy and tool. There is therefore the need for CE-specific indicators which may form the basis of a new certification scheme towards evaluating the circularity of a process, activity or even a product. This is a potential future work that can aid the transition towards a circular economy.

6.3.6 Limited sample size and choice of stakeholders

The spread of stakeholders interviewed during the course of the research was confined to limited professionals within the metal industry. For instance, getting access to policy makers within the metal industry was a difficult proposition due to the extremely tight schedules of the targeted individuals. Getting access to a wide range of stakeholders would have enhanced the richness of the qualitative interviews whilst providing further useful insights into the concept under investigation. From the quantitative aspect of the work, not all important and key stakeholders were reached with the view to ascertain their perception towards a circular economy in the metal sector. For example, the current work provides a very accurate measure in terms of views and perception of a given set of specific stakeholder, but do not allow for the expansion of the interview to cover a wider spectrum of stakeholders who may provide a very different picture or show resistance or lack of understanding to the concept of circular economy.

A case in point pertains to instances where the view of financial experts on issues such as the risk associated with the demand for investments for infrastructures (e.g. Eco industrial parks) and cleaner technologies to set up CE practices may become so huge thereby constituting a real barrier to a successful implementation. Issues such as this require the involvement of the financial and banking systems regarding the search for new forms of investments and business in CE practices. This is a key limitation which pertains to small sample size and choice of key stakeholders who were interviewed. More interviews across a wider spectrum of financial expert, supply chain managers, procurement managers, policy and decision makers and allied professionals within the metal industry should be carried out. This will provide a larger pool of qualitative dataset from which plenty other themes which weren't initially envisaged will emerge.

6.3.7 Driving power of consumer behaviour

As the saying goes-in a free market society, consumer is the king. For any policy initiative to see the light of the day, consumers are a key driver. A number of studies have submitted that consumers are not likely to pay more for products that stems from the principle of circular economy such as remanufactured or recycled products. This suggests that companies embarking on such remanufacturing strategies have to maintain the costs associated with recovery and reproduction below their original manufacturing expenditures. This is a difficult feat to attain given that additional logistics such as collection of products, disassembly, remanufacturing and delivery are involved. In the context of the current work, aspects pertaining to consumer choices which are driven by other factors other than environmental issues as highlighted above are not captured within the overall framework. The need to consider other consumer-induced factors such as preference, lifestyles and consumption pattern would constitute an invaluable future research to explore.

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APPENDICES

Appendix A: Ecoinvent processes and comments

1. ECOINVENT PROCESSES AND COMMENTS ON COPPER

Copper Primary

- 1363- Natural gas, burned in industrial furnace >100kW: The module includes fuel input from high pressure (RER) network, infrastructure (boiler), emissions to air, and electricity needed for operation.

- 301- Oxygen, liquid, at plant: Electricity for process, cooling water and waste heat. Infrastructure for air separation plant. The liquefaction process of air represents an average cryogenic air separation process.
- 479 -silica sand, at plant: includes the raw material "sand, at plant", a certain additional amount of conveyor belt and the energy for drying the sand.
- 529- Limestone, milled, packed, at plant: includes the packing and one part of the total heating energy for "production" and "administration".
- 606- Electricity, high voltage, production UCTE, at grid: Included are the electricity production in UCTE, the transmission network and direct emissions to air (ozone and N2O). Electricity losses are accounted for. Average technology used to transmit and distribute electricity. Includes underground and overhead lines.

- 848- Hard coal, burned in industrial furnace 1-10MW: Industrial heat production. The module describes the combustion process and includes softened water requirement, coal transport, ash disposal and electricity requirement.
- 985- Electricity, hydropower, at run-of-river power plant: This module describes a representative mix of 4 Swiss and 1 Austrian run-of-river power plants. It includes the area occupied; lubricant oil; mass of water passing through the turbines. Lifetime is assumed to be 80 years. Net average efficiency is 82% (best efficiency can be 88%).
- 1061- Anode, aluminium electrolysis: Includes anode production (with it's plant), transports of materials to the plant and the disposal of the wastes.
- 1076- Copper concentrate, at beneficiation: The module includes a mining and a beneficiation step with the mining infrastructure and disposal of overburden and tailings. Mining is done 70% open pit and 30% underground, followed by joint beneficiation of copper and molybdenite trough flotation, where considerable amounts of agents are added. Overburden and tailings are disposed near the mining site.

- 1093- Copper, SX-EW, at refinery: The module includes the mining of the ore including the mining infrastructure, the leaching and extraction, the electro winning and the disposal of the leaching residues.
- 1119-non-ferrous metal smelter: Includes facilities for roasting, electrolysis and for the blast furnace and converter processes.

- 1589- Heavy fuel oil, burned in industrial furnace 1MW, non-modulating: Direct air emissions from combustion, including infrastructure, fuel consumption, waste and auxiliary electricity use.

- 2210-disposal, nickel smelter slag, 0% water, to residual material landfill: Waste-specific short-term emissions to water from leachate. Long-term emissions from landfill to ground water.
- 2281-treatment, sewage, unpolluted, to wastewater treatment, class 3: Infrastructure materials for municipal wastewater treatment plant, transports, dismantling. Land use burdens. Wastewater purified in a medium size municipal wastewater treatment plant (capacity class 3), with an average capacity size of 24900 per-captia-equivalents PCE. Wastewater contains (in kg/m3). Three stage wastewater treatment (mechanical, biological, chemical) including sludge digestion (fermentation)

Copper Secondary

- 693- Electricity, production mix UCTE: It includes the shares of national electricity production of UCTE member countries (in 2000) at the busbar. It does not include transformation, transport nor distribution losses.

- 8146-facilities anode refinery, secondary copper: Construction of facilities and housing, and their disposal. No transports and construction work considered. Production of twin anode casting wheel and electrolytic cells: chromium steel, refractory bricks and concrete foundation. Building hall houses the facilities, covering 6883m2. Service lifetime 30 years, yearly capacity of 230'000 t copper refined.

- 8139-metal values from electric waste, in blister-copper, at converter: Inculdes the processing of e-scrap in the Boliden process by the Kaldo plant and the converter aisle. The multi-output-process "secondary copper conversion" delivers the co-products "metal values from electric waste, in blister-copper, at converter" and "lead, secondary, from electronic and electric scrap recycling, at plant".
  Tech: Conversion of Copper in a Kaldo Converter and treatment in converter aisle.

- 1351-heat, natural gas, at industrial furnace >100kW: The module includes fuel input from high pressure (RER) network, infrastructure (boiler), emissions to air, and electricity needed for operation.

- 350-sulphuric acid, liquid, at plant: Inventory Includes the obtention of SO2-containing gas (by means of oxidation of the sulphur containing raw materials: elemental sulphur, pyrites, other sulphide ores or spent acids). It includes also the convertion of SO2 to SO3 and the absorption of SO3 into solution (sulfuric acid in water) to yield Sulphuric acid. Manufacturing process starting with sulphur-containing raw materials (elemental sulphur, pyrites, ores and spent acids) is considered, plus consumption of auxiliaries, energy, infrastructure and land use, as well as transportation of raw materials, auxiliaries and wastes. Emissions to air are considered as emanating in a high population density area. Emissions into water are assumed to be emitted into rivers. Wastes are assumed to be sent to landfill.

- 2290-water, completely softened, at plant: Use of chemicals and some emissions for the treatment of water used in power plants. Water treatment by ion-exchanger for the use as cooling water in power plants.

2. ECOINVENT PROCESSES AND COMMENTS ON NICKEL

Nickel

1065- blast oxygen furnace converter

1098 -ferronickel, 25% Ni, at plant: The module includes a mining and a beneficiation step with the mining infrastructure. Subsequently it includes the metallurgy step with the disposal of slag and the metallurgical infrastructure. Production, application and emissions of most agents and additives used in beneficiation and metallurgy are also included.

The module describes the global production mix for ferronickel in 1994. It is designed for the use of the metal as raw material in the manufacturing of stainless steels and alloys. It is not to be used if the impact of ferronickel is considered to be high. In such cases, a more detailed analysis has to be conducted. The data used is mainly based on a study of the energy and material streams resulting from the production of class I nickel. Lacking data mainly on direct process specific emissions were taken from similar processes for copper winning.

1100 -iron ore, 65% Fe, at beneficiation

1101- iron scrap, at plant

1132 -pig iron, at plant

2160 - disposal, basic oxygen furnace wastes, 0% water, to residual material landfill

2204 -disposal, dust, unalloyed EAF steel, 15.4% water, to residual material landfill

2073- disposal, inert waste, 5% water, to inert material landfill

523 - dolomite, at plant

664-electricity, medium voltage, production UCTE, at grid

832- hard coal coke, at plant

1320- natural gas, high pressure, at consumer

301-oxygen, liquid, at plant

474- quicklime, in pieces, loose, at plant

1966- transport, barge

1968 -transport, transoceanic freight ship

1983- transport, freight, rail

1943 - transport, lorry >16t, fleet average

3. Ecoinvent processes and comments for lead

Primary Lead

- 7162 - Disposal, lead smelter slag, 0% water, to residual material landfill GLO: Waste-specific short-term emissions to water from leachate. Long-term emissions from landfill to ground water.
- 664 - Electricity, medium voltage, production UCTE, at grid (UCTE): Included are the electricity production in UCTE, the transmission network and direct SF6-emissions to air. Electricity losses during medium-voltage transmission and transformation from high-voltage are accounted for.This dataset describes the transformation from high to medium voltage as well as the transmission of electricity at medium voltage.
- 848- Hard coal, burned in industrial furnace 1-10MW: Industrial heat production. The module describes the combustion process and includes softened water requirement, coal transport, ash disposal and electricity requirement.
- 1589- Heavy fuel oil, burned in industrial furnace 1MW, non-modulating: Direct air emissions from combustion, including infrastructure, fuel consumption, waste and auxiliary electricity use.
- 1100 - Iron ore, 65% Fe, at beneficiation: Milling and sorting of crude ore.This ore has different grain sizes. It can be lump ore that can be used directly in the blast furnace or it can be ore of smaller grain size that is used for sinter and pellet production. Milling and mechanical sorting. Average iron yield is 84%.
- 1104- Lead concentrate, at beneficiation: The module includes the mining and the beneficiation step with the mining infrastructure and disposal of overburden and tailings (see part "Auxiliary Processes"). The module describes the global production mix for jointly produced zinc- and lead-concentrates from sulphidic deposits. The multioutput-process “exploitation, zinc-lead-deposit” delivers the three co-products “lead, concentrate, at beneficiation” and “zinc, concentrate, at beneficiation”. It is designed for the use of the concentrates as raw material for the ultimate production of lead and zinc.
- 10966 - Resource correction, PbZn, silver, negative & 10967 - resource correction, PbZn, lead, positive: This dataset is designed to adjust resource demand in multi-

output processes with mixed allocation schemes for resources (physical) and others (economical). In cases where the the upstream concentrate-inventory is allocated by economic criterias, the resouce demand of the individual refernece flos does not reflect the physical reality. Therefore the resource allocation is adjusted using this dataset in a way, that the resource demand of the specific reference flows from the multi-output process reflect the effective material composition.

- 529 limestone, milled, packed, at plant: includes the packing and one part of the total heating energy for "production" and "administration"
- 1363 natural gas, burned in industrial furnace >100Kw: The module includes fuel input from high pressure (RER) network, infrastructure (boiler), emissions to air, and electricity needed for operation.
- 300 nitrogen, liquid, at plant: Electricity for process, cooling water and waste heat. Infrastructure for air separation plant. The liquefaction process of air represent an average cryogenic air separation process. As products only liquid nitrogen, liquid oxygen and liquid crude argon were considered. No gaseous product considered. The allocation factors were calculated from the heat of vaporisation and the specific heat capacity multiplied with the temperature difference from 20°C to the boiling point. Multi output process. The allocated outputs are liquid nitrogen, liquid oxygen and liquid crude argon.
- 301 oxygen, liquid, at plant: Electricity for process, cooling water and waste heat. Infrastructure for air separation plant. The liquefaction process of air represent an average cryogenic air separation process. As products only liquid nitrogen, liquid oxygen and liquid crude argon were considered. No gaseous product considered. The allocation factors were calculated from the heat of vaporisation and the specific heat capacity multiplied with the temperature difference from 20°C to the boiling point. Multi output process. The allocated outputs are liquid nitrogen, liquid oxygen and liquid crude argon.
- 479 silica sand, at plant: includes the raw material "sand, at plant", a certain additional amount of conveyor belt and the energy for drying the sand. No requirements for administration are included. There is almost no difference from the module "sand, at mine". Some more transportation and energy for drying is added. For the calculation of the additional requirement of conveyor belt the total yearly production of a German company (450'000 tons) and a lifespan of 20 years are used.
- 1983 transport, freight, rail: The module calls the modules 'operation of vehicle'; 'production, maintenance and disposal of vehicles'; 'construction and maintenance and disposal of railway tracks'. Inventory refers to the entire transport life cycle. For rail infrastructure, expenditures and environmental interventions due to construction, renewal and disposal of roads have been allocated based on the Gross tonne kilometre performance. Expenditures due to operation of the rail infrastructure, as well as land use have been allocated based on the yearly train kilometre performance.
- 1943 transport, lorry >16t, fleet average: operation of vehicle; production, maintenance and disposal of vehicles; construction and maintenance and disposal of road. Inventory refers to the entire transport life cycle. For road infrastructure,

expenditures and environmental interventions due to construction, renewal and disposal of roads have been allocated based on the Gross tonne kilometre performance. Expenditures due to operation of the road infrastructure, as well as land use have been allocated based on the yearly vehicle kilometre performance. For the attribution of vehicle share to the transport performance a vehicle life time performance of 540000 tkm/vehicle has been assumed.

Secondary Lead

- 2210- Disposal, nickel smelter slag, 0% water, to residual material landfill: Waste-specific short-term emissions to water from leachate. Long-term emissions from landfill to ground water.
- 693- Electricity, production mix UCTE: It includes the shares of national electricity production of UCTE member countries (in 2000) at the busbar. It does not include transformation, transport nor distribution losses.
- 8145- Facilities blister-copper conversion, secondary copper: Construction of facilities and housing, and their disposal. No transports and construction work considered. Production of Kaldo converter and converter aisle: chromium steel, refractory bricks and concrete foundation. Building hall houses the facilities, covering 1200m2. Service lifetime 50 year. Service lifetime 50 year, 250'000 t of metals produced per year.
- 475- Quicklime, milled, loose, at plant: Includes the processes: crushing, milling, filtering (cyclone), dedusting, transportation, and storing. One part of the total heating energy for "production" and "administration" is included. Equipment included in the infrastructure: 1 crusher, 1 roller mill, 1 plant for dedusting, 1cyclone, and 1 small silo.
- industrial machine, heavy, unspecified, at plant, conveyor belt, at plant, electricity, hydropower, at run-of-river power plant, electricity, medium voltage, at grid, light fuel oil, burned in boiler 100kW, non-modulating, quicklime, in pieces, loose, at plant.

4. ECOINVENT PROCESSES AND COMMENTS ON STEEL

Steel Primary

1065- blast oxygen furnace converter

1098 -ferronickel, 25% Ni, at plant

1100 -iron ore, 65% Fe, at beneficiation

1101- iron scrap, at plant

1132 -pig iron, at plant: Blast furnace process. Emissions are abated. Inputs and air emissions from different sources. Transports of iron ore calculated according to information about exports and imports.

2160 - disposal, basic oxygen furnace wastes, 0% water, to residual material landfill: Waste-specific short-term emissions to water from leachate. Long-term emissions from landfill to ground water. Expenditures for solidificalion with cement (user-specified option)

2204 -disposal, dust, unalloyed EAF steel, 15.4% water, to residual material landfill: dust from carbon and un-alloyed electric arc furnace steel production. Waste-specific short-term emissions to water from leachate. Long-term emissions from landfill to ground water.

2073- disposal, inert waste, 5% water, to inert material landfill: landfill with renaturation after closure. 50% of the sites feature a base seal and leachate collection system.

523 - dolomite, at plant: construction materials, Raw materials, machineries and energy consumption for production, estimated emissions to air from production and infrastructure of the site (approximation). No water emissions.

664-electricity, medium voltage, production UCTE, at grid

832- hard coal coke, at plant: The coking has been considered as a black box. The energy necessary for the process is assumed to be provided by part of the input coal and by some electricity. The module includes chemicals used for operation and the associated transport requirements. The transports of coke are considered to be negligible, because the plant is assumed to be coal mine-mouth. The module also includes the total emissions to air and water from the entire plant. Coke oven gas, tar, and benzene are byproducts of coking.

The multioutput-prozess "hard coal, in coke plant" delivers the coproducts "coke oven gas, at plant", "tar, at coke plant", and "benzene, at coke plant". 79.8% of the total energy and material input as well as emission from the coke plant are allocated to coke production, 15% to coke oven gas production, 4.1% to tar production, and 1.1% to benzene production. This allocation has been performed considering the energy content of the coke compared to all other byproducts. Hard coal coke is assumed to have a low heating value 28.6 MJ/kg and bulk density is 530 kg/m3.

1320- natural gas, high pressure, at consumer: This dataset describes the energy requirements and the emissions of the high pressure distribution network in Europe.

Total network losses are based on assumptions, repartition of losses on high and low pressure network on calculations with data for other countries.

301-oxygen, liquid, at plant: construction materials. Includes the calcination process. Also included is the electricity consumption for preheating of the heavy fuel oil and one part of the total heating energy for "production" and "administration". Equipment included in the infrastructure: 2 vertical kilns; not included is the use of fireproof bricks since no data are available. Only the measured emissions are included.

474- quicklime, in pieces, loose, at plant

1966- transport, barge: transport systems, The module calls the modules addressing: operation of vessel; production of vessel; construction and land use of port; operation, maintenance and disposal of port. In addition canal construction and maintenance are called.

Inventory refers to the entire transport life cycle. Port infrastructure expenditures and environmental interventions are allocated based the yearly throughput (0.14). Vessel manufacturing is allocated based on the total kilometric performance (1'240'000km) and its transport performance (1000/unit).

1968 -transport, transoceanic freight ship: The module calls the modules addressing: operation of vessel; production of vessel; construction and land use of port; operation, maintenance and disposal of port.

Inventory refers to the entire transport life cycle. Port infrastructure expenditures and environmental interventions are allocated based the yearly throughput (0.37). Vessel manufacturing is allocated based on the total kilometric performance (2'000'000km) and its transport performance (50000/unit). For each transport activity 2 ports are required.

1983- transport, freight, rail:

1943 - transport, lorry >16t, fleet average

Steel Secondary

1061-anode, aluminium electrolysis

1094-electric arc furnace converter: (Metals extraction) Infrastructure for input material unloading and storage, for EAF processes and casting and for administrative buildings

1101- iron scrap, at plant

2204- disposal, dust, unalloyed EAF steel, 15.4% water, to residual material landfill

2205- disposal, slag, unalloyed electr. steel, 0% water, to residual material landfill: slag from un-alloyed electric arc furnace steel production. Waste-specific short-term emissions to water from leachate. Long-term emissions from landfill to ground water.

2073- disposal, inert waste, 5% water, to inert material landfill

664-electricity, medium voltage, production UCTE, at grid

834-hard coal mix, at regional storage (hard coal, fuels): Country-specific supply of coal by producing regions. The module includes all transport from the storage in producing regions to power plants in the specific country.

For each exporting region, average transport distances specific for the country have been estimated. Dust from transport and load/unload operations is included. Average coal losses are considered. Average emissions to water due to leaching from coal heaps at storage at receiving terminal is estimated from the literature.

1320-natural gas, high pressure, at consumer

301-oxygen, liquid, at plant

474-quicklime, in pieces, loose, at plant

497-refractory, basic, packed, at plant: construction materials, Includes the whole manufacturing process, internal processes (transport, etc.), packing and infrastructure. No administration is included.

1983-transport, freight, rail

1943-transport, lorry >16t, fleet average

Appendix B: Additional work-Virgin Vs Recycled Polystyrene Slabs
Introduction

This case study is centred on the environmental performance of two insulation materials. The first material is made from virgin raw material in a linear supply chain. The second material is made from 100% recycled material representing a circular supply chain.

Polystyrene is a synthetic aromatic polymer. It is made primarily from the monomer styrene which is a liquid petrochemical. Polystyrene is used for packaging. Polystyrene may be in foam state or rigid. Polystyrene can be in the form of general purpose polystyrene (GPPS), extruded polystyrene (XPS), and high impact polystyrene (HIPS). Expandable Polystyrene or EPS is a lightweight thermoplastic product that is also strong, offering outstanding thermal insulation, it is therefore ideal for the construction and packaging industries. Polystyrene slabs are used as insulation between and on the rafters, the upper floor ceiling, the basement floor and the outer walls, as well as pipe, and sound insulation.

Polystyrene market

Polystyrene is a main raw material used by the packaging, construction, electronics and consumer goods & appliances industries. The Packaging function accounts for around one-third of global polystyrene use at 37.6% in 2014. The polystyrene market is forecasted to grow at an annual growth rate of 5.1% reaching a staggering $USD 28 billion by 2019 (marketsandmarkets.com, 2015). Industrialisation is a major driver of the polystyrene industry, in addition to increased consumption in the emerging economies across the world as well as the uneconomic nature of polystyrene substitutes.

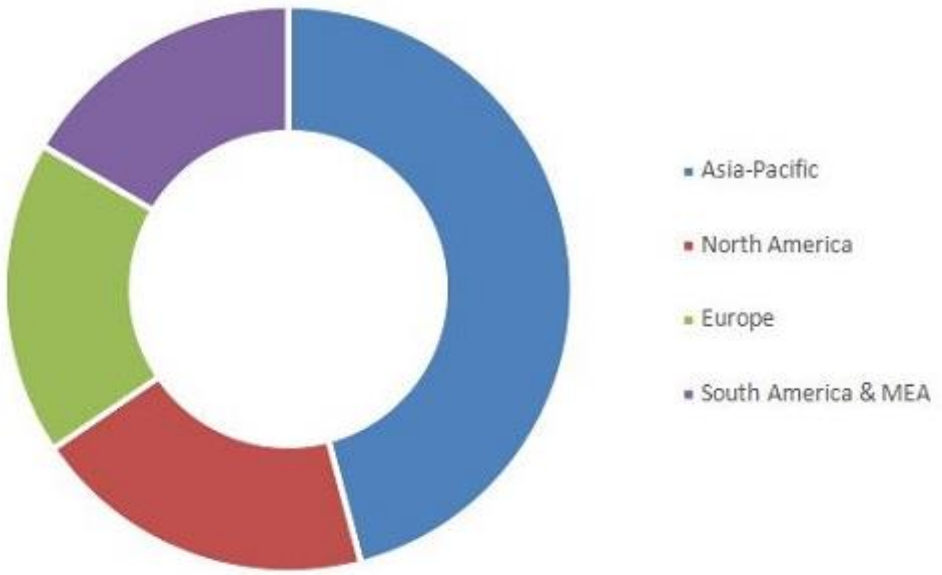

Figure 1: Polystyrene market share by region, 2014, slab supply chain Source: Markets and markets analysis, 2015

2. The manufacturing process

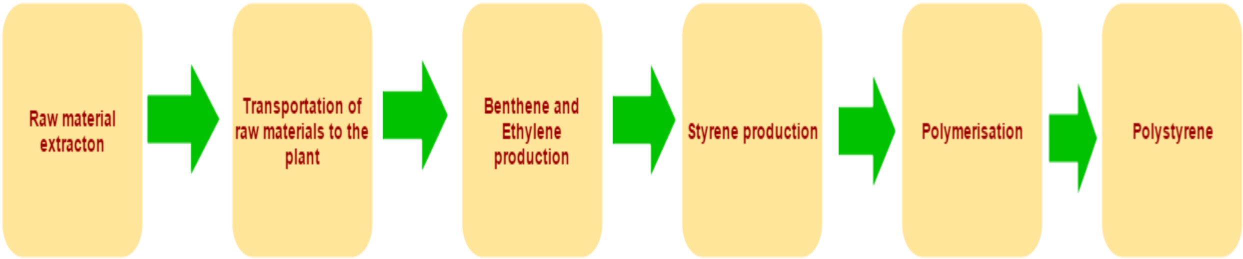

Figure 2: Polystyrene slab supply chain

Fig 1 above shows the production process of Polystyrene foam slab using virgin polystyrene. (PS).

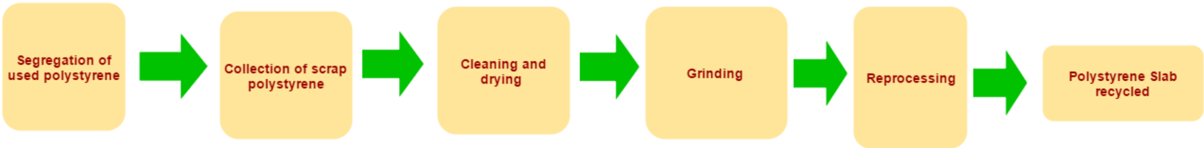

Figure 3: Polystyrene slab (100% recycled) supply chain

Fig 2 above shows the production process of Polystyrene foam slab using scrap polystyrene. (PSre).

3. Data Collection

Emissions Data for PS and PSR was sourced from secondary means i.e. Ecoinvent database 2010. The Ecoinvent database has over 20 years of experience in LCA data compilation and this is the reason why it has been used in this study. The following exact information is retrieved from the Ecoinvent 2010 database:

- Unit process data that provides the quantity and unit of measure of processes
- The impact categories in the CML Baseline 2001 methodology which include global warming (GWP 100) (GWP), acidification (AP), eutrophication (EP), ozone layer depletion (ODP), photochemical oxidation (POCP), human toxicity (HTP), fresh water aquatic ecotoxicity (FAETP), marine aquatic ecotoxicity (MAETP), and terrestrial ecotoxicity (TETP).
- Eco-indicator 99 that comprise ecosystem quality, human health and resources.Eco-indicator 99 ecosystem quality comprise: acidification, eutrophication and land occupation. Eco-indicator 99 Human health comprises: carcinogenics, climate change, ionising radiation, ozone layer depletion and respiratory effects.Eco-indicator 99 ecosystem resources comprise: fossil fuels, and mineral extraction.

4.Data Analysis

The results compare the carbon emissions implications of producing Polystyrene foam slab using virgin polystyrene (PS) through a linear production system to the production of Polystyrene foam slab using a hundred percent recycled polystyrene scrap (PSre) through a circular supply chain. Fig 1 illustrates this comparison.

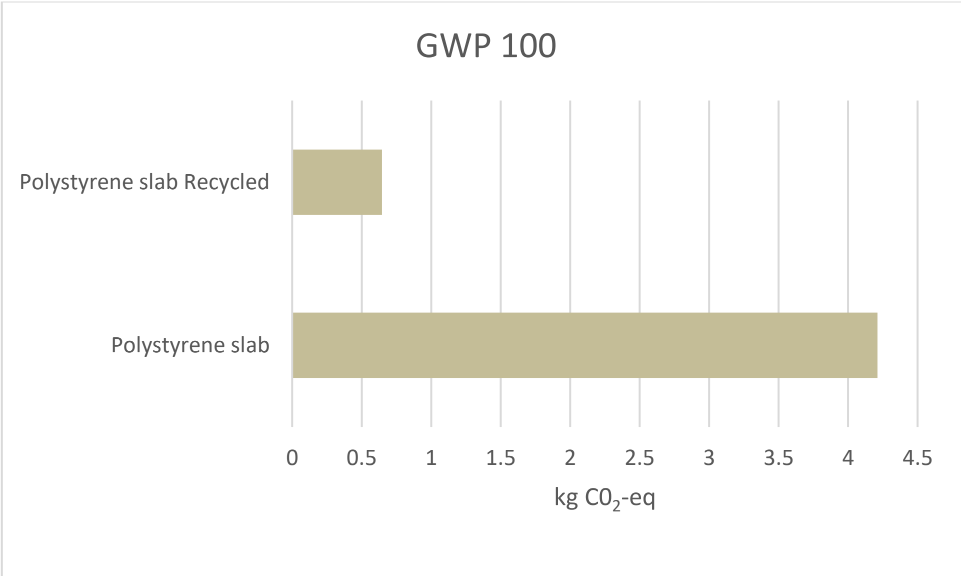

Fig 4. Comparative level of Carbon emissions by PS and PS-recycled.

The result shows that the carbon emissions from the supply chain of polystyrene are 4.2121 kg CO_2-eq while that of polystyrene slab-recycled is 0.6472 kg CO_2-eq. This represents around a 650% difference between the two supply chains and indicates that Polystyrene foam slab using a hundred percent recycled polystyrene scrap (PSre) through a circular supply chain is significantly lower than that of the produced using virgin polystyrene (PS) through a linear production system.

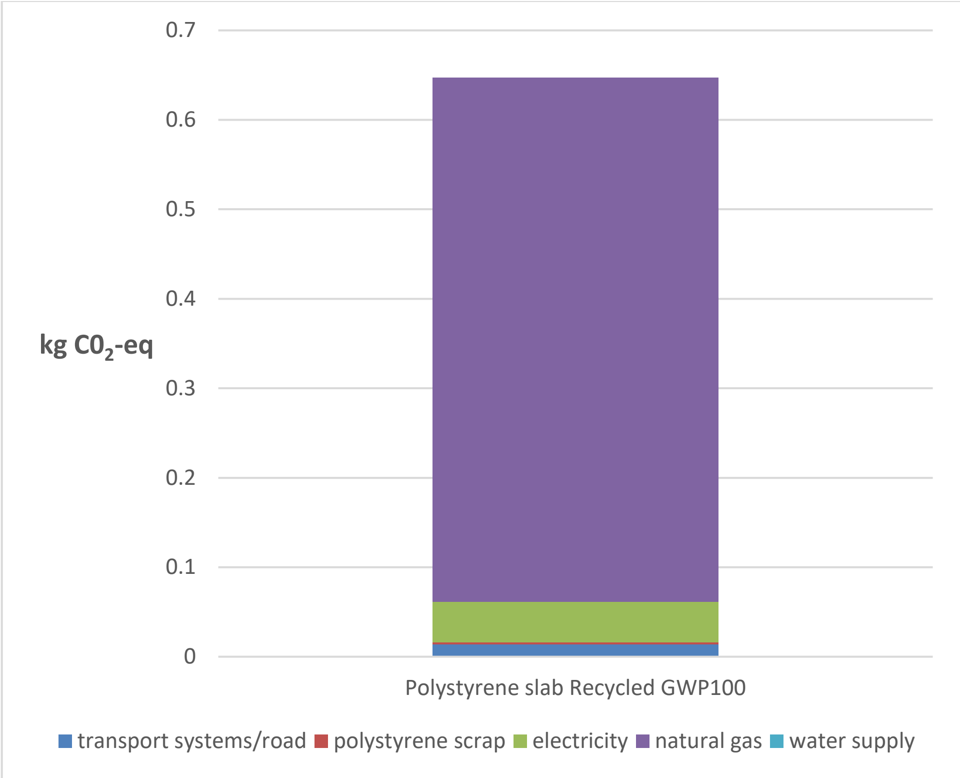

Fig 5. Breakdown of carbon emissions for PS-re

The breakdown of CO_2 emissions for PS-re shows that the main carbon hotspot is natural gas. This contributes 91% of total carbon emissions. Electricity contributes the second highest amount at 7%. Transportation of polystyrene scrap makes up 2% while water usage and polystyrene scrap contribute less than one per cent respectively.

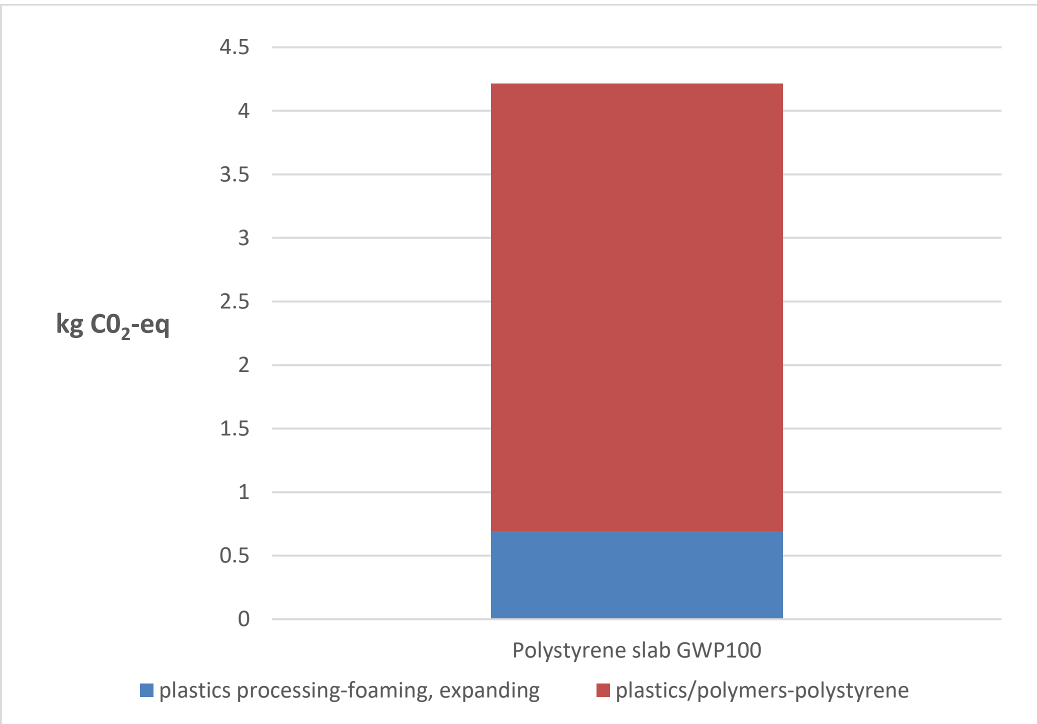

Fig 6. Breakdown of carbon emissions for PS

From Fig 6, it is observed that polystyrene production is the main carbon hotspot of polystyrene slab. It contributes 84 % of total carbon emissions. This includes all processes from raw material extraction, to production by suspension polymerization out of benzene and ethylene until delivery to plant. It is a highly energy intensive process. This is followed by processing of the polystyrene into slabs. This includes foaming and expanding with emissions of 0.6938 kg CO_2-eq, contributing the remaining 16 % of total carbon emissions.

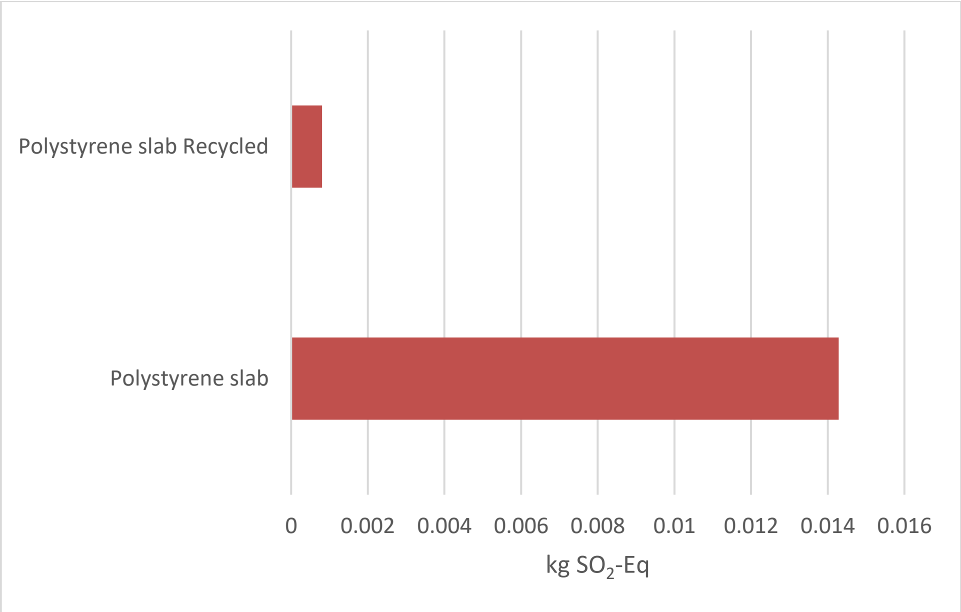

Fig 7. Acidification potential PS vs PS-recycled

Examining another impact indicator, acidification potential, we see that Polystyrene slab-recycled outperforms polystyrene slab. Polystyrene slab-recycled is responsible for 0.0008 kg SO_2-Eq compared to 0.0143 kg SO_2-Eq by polystyrene slab, equating to an estimated 1687.5% increase difference between the two.

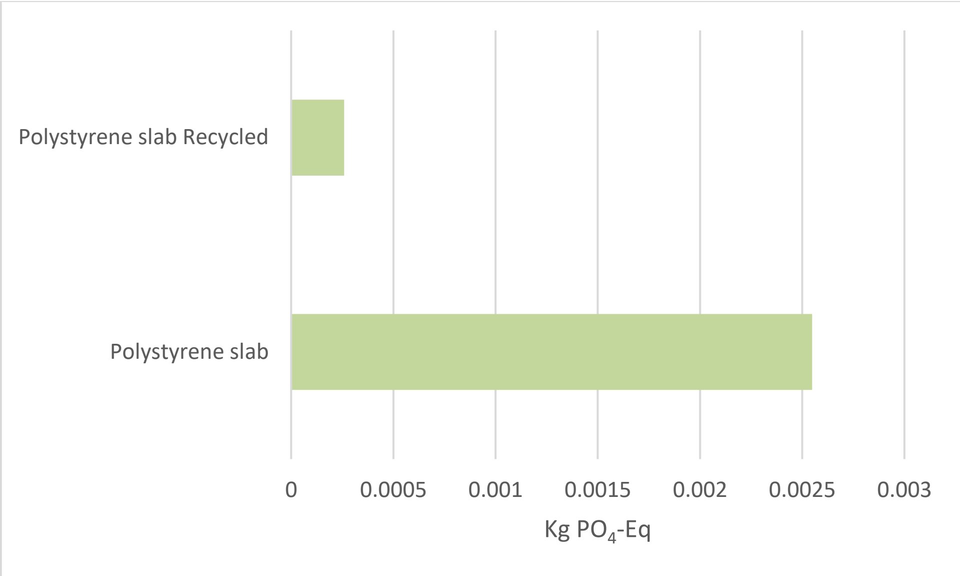

Fig 8: Eutrophication potential of PS vs PS-recycled

The breakdown of eutrophication potential for both polystyrene slab and polystyrene slab-recycled is presented in Fig. 8. It can be observed from the graph that polystyrene slab (0.0025 kg PO_4-Eq) contributes significantly more than polystyrene slab-recycled (0.0003 kg PO_4-Eq) in terms of eutrophication potential.

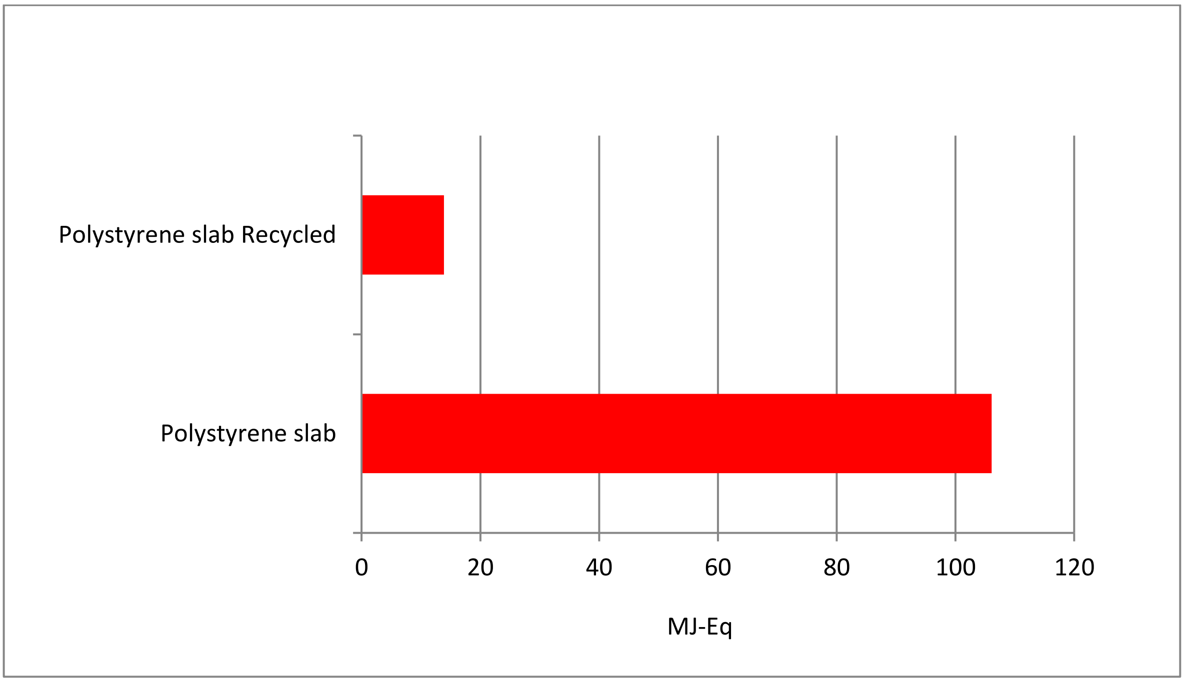

Fig 9 Cumulative energy comparison PS vs PS-recycled

Fig 9 compares cumulative energy demand between polystyrene slab and recycled polystyrene slab production. Recycled polystyrene slab production uses 13.8993 MJ-eq of energy compared to 106.0815 MJ-Eq of energy used in polystyrene slab production. In other words, recycled polystyrene slab production uses approximately only 13% of cumulative energy required for polystyrene slab production.

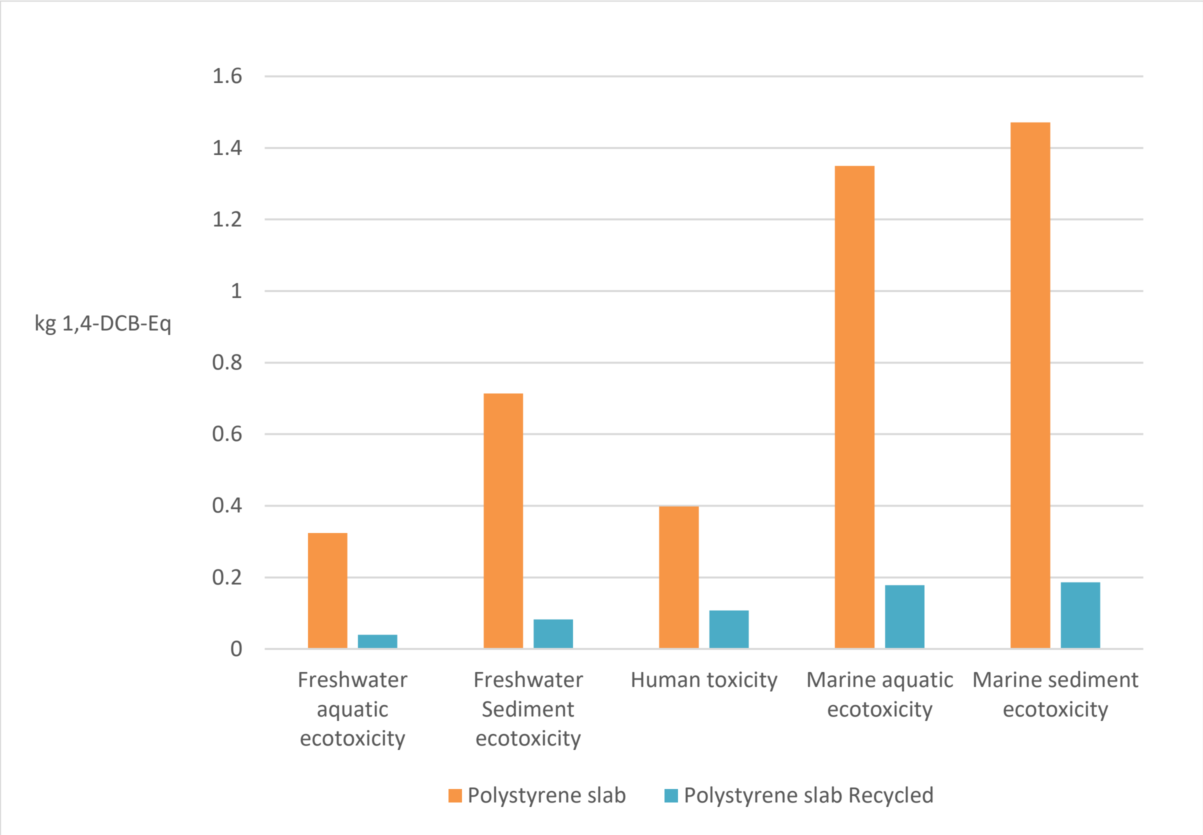

Fig 10: Ecotoxicity PS vs PS-recycled

Fig 10 presents the comparative analysis of polystyrene slab and polystyrene slab-recycled across five exotoxicity indicators based on the CML2001 method (Guinee, 2002). It can be seen that polystyrene slab performs in a less environmentally friendly manner in all of the exotoxicity indicators.

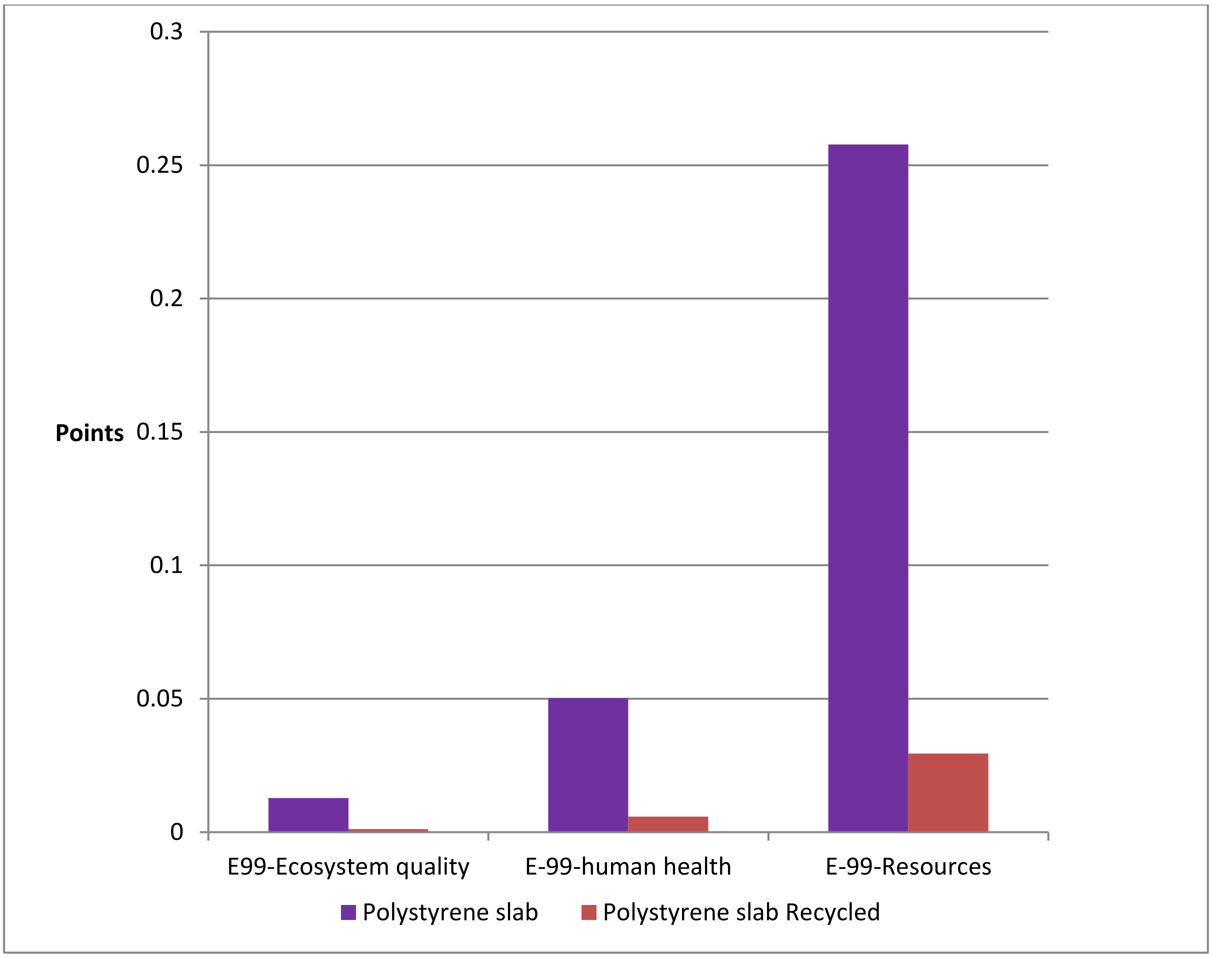

Fig 11: E-99 Indicators comparison PS vs PS-recycled

In terms of Eco-indicator 99 impacts that comprise ecosystem quality, human health and resources, recycled-polystyrene slab production also has significantly less impacts on the environment compared to virgin polystyrene slab production.

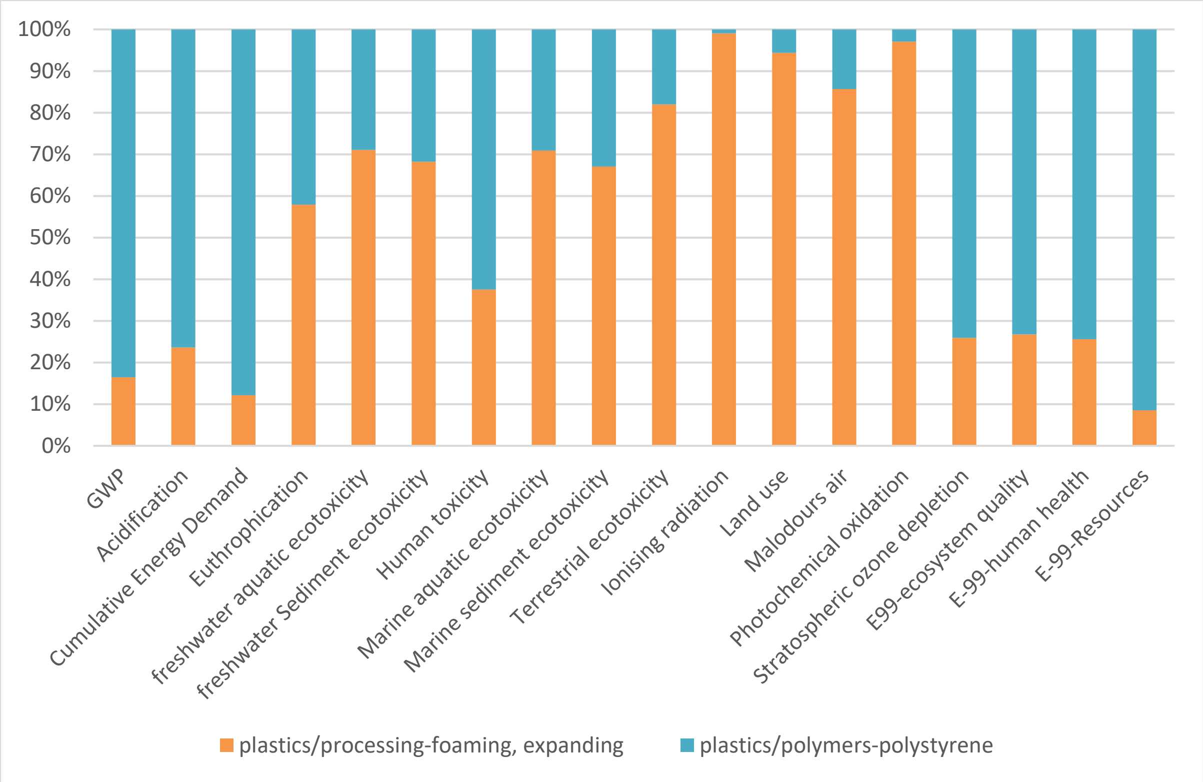

Fig 12: Environmental profile of PS

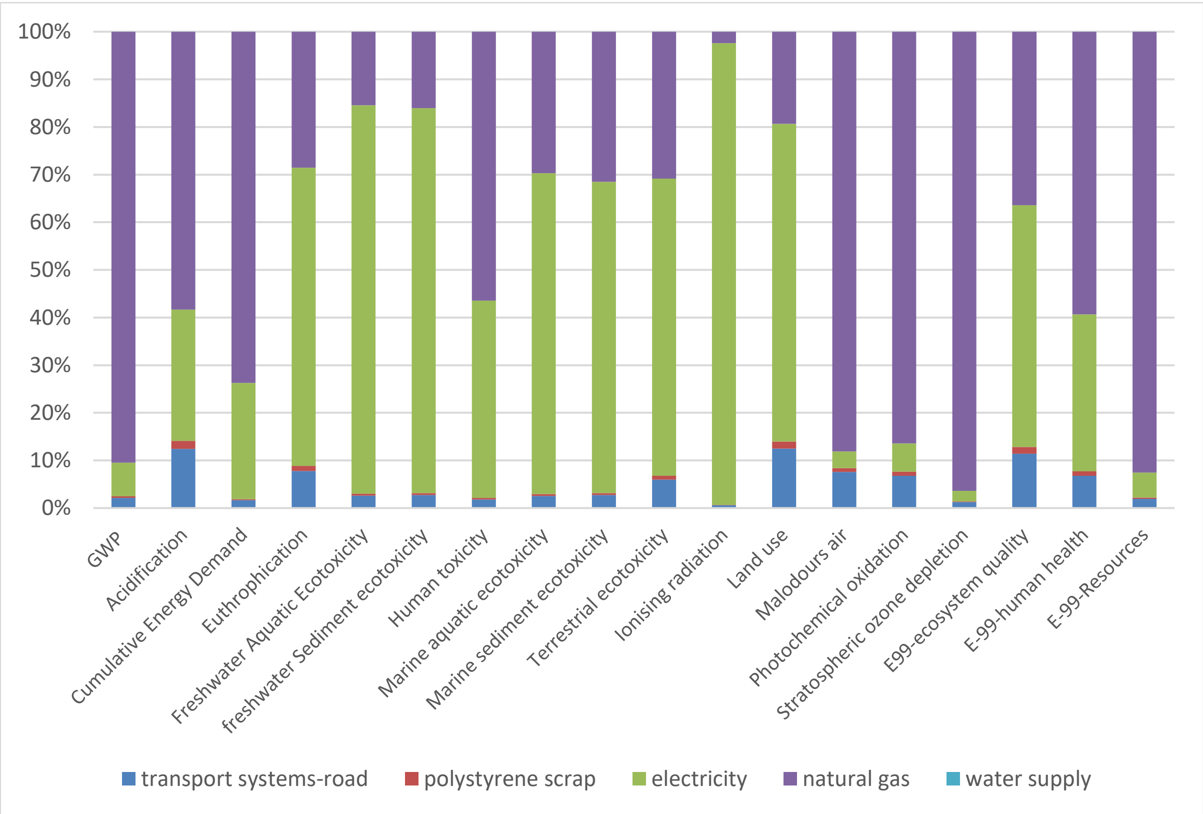

Fig 13: Environmental profile of PS-recycled

5. Environmental profile

Fig. 12 and 13 show the environmental profiles of polystyrene slab and 100 % recycled polystyrene slab respectively. All impact indicators have been normalised and the total of each impacts equal to a 100%. In Fig 12, polystyrene production is the most significant contributor in polystyrene slab production for ten of the eighteen indicators. polystyrene production includes all processes from raw material extraction, to production by suspension polymerization out of benzene and ethylene until delivery to plant. It contributed ionising radiation (99%), photochemical oxidation (97%), land use (94%), malodours airs (86%), terrestrial ecotoxicity (82%), fresh water aquatic ecotoxicity (71%), marine aquatic ecotoxicity (71%), fresh water sediment ecotoxicity (68%), marine sediment ecotoxicity (67%), and eutrophication (52%).

Furthermore, processing of the polystyrene into slabs which includes foaming and expanding accounts for the remaining indicators. It contributed global warming potential (84%), cumulative energy demand (88%), acidification (76%), stratospheric ozone depletion (74%), human toxicity (62%), E-99 ecosystem quality (73%), E-99 human health (74%), and E-99 resources (91%). Even though processing of the polystyrene into slabs contributes to fewer indicators, it should be observed that it contributes to the most important indicators such as global warming potential, acidification and cumulative energy demand.

The environmental profile of 100 % recycled polystyrene slab is illustrated in fig 13. From Fig 13, is the two most significant contributors are natural gas and electricity. They both contribute in big and small amounts to all indicators. Natural gas contributed 90% of global warming (GWP100), acidification (58%), cumulative energy demand (74%), human toxicity (56%), malodours air (88%), photochemical oxidation (86%), stratospheric ozone depletion (96%), E-99 human health (59%), and E-99 resources (93%).

In addition, the second most significant contributor to inventory impacts is electricity use. Electricity use also contributes in some way to all impact indicators. Its highest contribution was ionising radiation (97%), fresh water aquatic ecotoxicity (82%), fresh water sediment ecotoxicity (81%), marine aquatic ecotoxicity (67%), land use (67%), marine sediment ecotoxicity (65%), eutrophication (63%), terrestrial ecotoxicity (62%), and E-99 ecosystem quality (51%).

ECOINVENT DATABASE PROCESSES AND COMMENTS Polystyrene Slab and Polystyrene Slab 100 % Recycled

polystyrene, expandable, at plant, RER, [kg] (#1835)
Aggregated data for all processes from raw material extraction until delivery at plant production by suspension polymerization out of benzene and ethylene

polystyrene foam slab, at plant, RER, [kg] (#998)
Includes production and thermoforming of EPS

foaming, expanding, RER, [kg] (#1852)
This process contains the auxillaries and energy demand for the mentioned convertion process of plastics. production of insulation panels

natural gas, burned in boiler modulating >100kW, RER, [MJ] (#1362)
The module includes fuel input from high pressure (RER) network, infrastructure (boiler), emissions to air, and electricity needed for operation.

water, decarbonised, at plant, RER, [kg] (#2291)
Use of chemicals and some emissions for the treatment of water used in power plants. Water treatment in power plants by precipitation or carbonates for the use as cooling water.

electricity, low voltage, at grid, CH, [kWh] (#752)
includes the transmission network infrastructure and emissions from transmission at low voltage. SF6 and losses accounted for. sulphur hexafluoride, liquid, at plant, distribution network, electricity, low voltage

polystyrene scrap, old, at plant, CH, [kg] (#11793)
Includes the collection and transport of post-consumer scrap from dismantling to scrap dealer. Based on the Ecoinvent data from disposal, building, polystyrene isolation, flame-retardant, to final disposal.

Appendix C: Interview transcripts

Interview with A-H, Quality and Environment Manager, T- limited, Metal Producer Stakeholder. 11/05/17 3pm

68mins

Regrinding operations

Used and worn tools come in and the tools get assessed to see if they have any usable life for regrinding. If there isn't it goes to scrap separated out by customer, if the customer requires we ship the scrap back to them otherwise we scrap it here. First it is stored before going back to our raw material provider for recycling. It gives us a cost saving and uses less virgin material getting an environmental benefit. You can't see any difference but the microstructure would be due to the impurities. There is an energy saving.

Can you give us a bit of background about yourself?

I've been at Technicut for 4 years. I have been working in the metal bashing industry for 10 years. I started out in orthopaedic implants doing forging and casting of materials. I have a software engineering degree and ended up working in an engineering firm.

What is your understanding of the concept of CE?

I hear the term a lot. Effectively it is **minimising the impact of our use of resources has**. It might not be taking a material right back to its origin but **increasing the life** and or **reusability of that item or repurposing** it to another purpose entirely. It is about decoupling economic growth from resource consumption.

CE is definitely desirably. Not necessarily from a purely environmental point of view, **it also makes economic sense**. As we saw with our dual ended blanks, we can get products quicker and cheaper by recycling the material apart from the environmental benefit. **Metals lend themselves to recycling unlike other materials**. All our material comes via Germany and Austria but the actual raw material is predominantly mined in China and a small percentage comes from Australia and the US. It is not a major issue presently but could be in the future if output is restricted or artificially inflating prices. Reusing and recycling material can protect us from security of supply concerns. We might now have much of an impact globally but every manufacturer engages in it, it can only help.

Is CE achievable?

Yes it is. We are already engaged in reuse, remanufacturing, repurposing and recycling. We only have regrinding contracts with a limited number of customers and not all products can be reground successfully **(Technical issues).** although it is desirable and we are doing it, there are a lot more things we need to do to improve that. About a third of our products get reground. There is a lot more scope for increasing the circularity of our resource loops.

Why do you think that is?

Some customers **just want their tools to be single use** and have taken a policy design. The cost and price is **cheaper for single use**. Some customers choose to do their **own regrinding in-house**. With our smaller customers, there is a **lack of sophistication** and **lack of administrative structure;** it is easier to scrap a tool and buy a new one than having someone managing the regrinding cycle and loops.

What are possible obstacles from engaging in CE?

In our industry, being able to regrind tools effectively requires **additional skill** and **technical knowledge** to be able to design the tools with regrinding in mind, to produce the tool reputably so that a regrind would function exactly like a brand new tool would. In the aerospace industry which is 90% of our business, they need the tools to function the same whether they are new or not. They need repeatability and assurance that everything will be exactly the same. I think that is lacking in other suppliers. The impression I get is that our smaller competitors **are lacking in process control and sophistication** to do that effectively.

What could drive more adoption of CE concepts?

I think our end customers are driving a lot of that. It is driven from a cost point of view. If the customer didn't want or need regrinding of the tools, we wouldn't offer it, even if there was a compelling economic argument. In terms of recycling materials to go back into the shank end of our tools, we would be doing that. The biggest drive would be economic and that would come from our raw material suppliers making materials and services available to us. Having them make it economically advantageous for us.

Do you consider the circularity or greenness when choosing the suppliers of your main raw materials?

Unfortunately here we only have 3 main suppliers and they are the only suppliers of the raw materials so we are restricted in where we can get it from. All three offer recycling services. Typically we focus on one supplier but do business withal three of them so as to avoid overreliance on one. They have a quick turnaround and offering dual grade blanks.

Given that your activities are customer driven, could you as a consumer (customer) exert the same pressure on your suppliers for them to source the raw materials in a more efficient circular way?

They haven't reacted in the past to that. We have switched our recycling processes. For example when recycling our carbine sludge whenever we grind stuff, little particles come off and mix with the oil and we have switched our supplier to send those to our raw material provider. Previously it was been processed in England, now it's going back to Austria. There is scope to push our suppliers to do more.

In your opinion, what policy instruments would be needed for the move towards a more CE?

I can't say that we have taken that much notice. The only regulation that was difficult for us was getting our raw material supplier registered as a waste carrier. It was very basic stuff. We do hold a legal register and abide by all the requirements. There is no regulatory incentive to recycle more. I hope what we are doing enough at the moment would satisfy any future regulation. **Any regulation that promotes more recycling and repurposing can only be a good thing**. We would embrace such new regulations, especially if it provides an economic advantage as well. It would restrict the market place as well if our customers were faced to choose companies that could re-service and repurpose tools, it would increase our business opportunities.

It is argued that there is a lack of leadership in terms of the move to a CE, what is your opinion?

In the aerospace industry, it is driven by the large OEM customers; Boeing, Rolls Royce etc. their **focus is predominantly production and cost**. In terms of CE, they are pushing for things like reduced tooling costs but they are not certainly focused on a CE. If they could do the same thing without repurposing they would be just as happy.

I think a bit of both public and private leadership is needed. I wouldn't want to promote too much government interference. **A quango** would be ideal as a go-between for government and private industry. From what I have seen lately of previous government legislation, it is not entirely practical to implement and **some cooperation** between government and industry would be the most practical way to do that. For example The Forestry commission, it is funded by government but does not report to the government. It is separate body. They are typically set up to take responsibility for public need. They are apolitical. You could set up a quango with the remit to promote CE and get funding from the government but not kicked around as a political football. They could take a linger view and have a longer relationship with industry. The Environment Agency is also a quango.

Is CE possible in a free-market economy given it has been more successful in planned economies?

The only way you can do it in a free market is probably **through economic subsidy**; making it commercially viable to do things likes co-location, cooperation between manufacturers that are ordinarily competitors and cooperation within the whole supply chain. I can see China can make decisions quickly. In the free-market it would be all **about the incentives**. Some short measure would need to become long term measures. There could be regulation. **Increase awareness** within the larger companies purchasing groups of the benefits of sustainability. If they are aware of the benefits of it, they are more likely to weight it more heavily in their decision making. Drive it from the top customers who can enforce it down their supply chain through their economic power. If you educate the big boys and they weight sustainability heavily in decisions, it would force the entire supply chain to act.

How is your interaction with other companies and stakeholders within the industry?

It tends to be very secretive. **There is a fair bit of interaction**. We are integrators for big companies likes Rolls Royce and Airbus which means that we are responsible for buying cutting tools for them so we supply with our own tools as well as buying our competitors tools that we don't make or don't want to make. There is a lot of interaction in that respect. Some of our competitors are integrators for other sites and are buying our tools for others. There is no association for precision metal cutting tools. There is the Cutlers association but it is not specific to us. I don't think an industry body would have the teeth to implement anything although it could encourage and educate.

We don't deal much with the local council. We tend to avoid them. They are ineffectual. We have zero support from the local council.

How do you deal with your scrap?

All of our raw material scrap goes either to a waste contractor or 90% of our scrap goes back to our main supplier for reprocessing. Even the sludge goes to the primary raw material supplier. The turnings from high speed steel go **to a local contractor**. We deal with **Frogsons** waste management company. They are big in south Yorkshire.

Could things be different after the UK leaves the EU?

We are already feeling **the negative impacts** of the referendum. We do business with partners across Europe and the uncertainty and currency exchange rate dip is making things more expensive for us. In terms of regulations, I don't think much will change. Most of the regulation we abide by is already EU regulation and if we intend to continue to do business with the EU, we will have to abide by their rules regardless of domestic rules.

Is there anything you would like to add?

I would be interested to see what other companies are doing and saying. We are partnering with other companies in Sheffield on manufacturing excellence. You should see **Gripple Ltd** based in Sheffield who deals in manufacturing of fastening of wires. They have expanded massively. It is an employee owned business.

TRANSCRIPT OF INTERVIEW WITH C-W PIEMA

(Environment Officer,)

Corporate consumers of metals as stakeholders in the metals waste reuse and recycling supply chain in the transition to a closed-loop/circular economy.

11am, Arts Tower, 25/05/17

INTRODUCTION

Key: Q: Question CW: Charlotte Winnert R: Response CE: circular economy

Introduction

Name: Charlotte Winnert PIEMA Years of experience: 10 years

Q: What is your role within the organization you are working for?

CW: Environment Officer, Recycling and waste management is a key part of my role

Q: Given your capacity as an environment officer within the University, how would you define Circular economy (CE)? Would a circular economy create a more sustainable society?

CW: it is basically about making sure that waste is reused and is put back in the economy, understanding the value of waste and making sure that supply chains are sustainable and reducing the environmental impacts of cradle to grave. It is ambiguous like the term sustainability.

Q: Given your understanding of the concept of Circular economy (CE), would you say it's desirable, possible, achievable and realisable?

CW: CE is desirable and possible but the economic structure in the world and the UK doesn't work, you can't have a capitalist approach where you get lots of the **"environment for free"** does not provide the mechanism to ensure that sustainability and CE really works. in order to move forward as an approach, you need to change the economic model of the world if we are to make any improvements. Capitalism is not the way forward. It is an external cost and it is free. While we get it free and not pay for it, businesses take advantage of that so the only way you can get Organisations thinking about is to start costing that resource in their economic model and there is no appetite to do that because essentially then you are placing boundaries on capitalism and profit is the god. Growth has been coupled with resource use instead measures such as standard of living, happiness etc. There was some appetite to do that when the Bruntland report came out and with the many sustainability conferences in the past but the appetite to do that has died and just some fiddling round the edges.

Q: Do you think the political system also does not help sustainability and CE?

CW: yes political systems can be a barrier to CE but I think fundamentally it is the economic model. The politicians are still functioning with the capitalist economic model.

Q: What opportunities does CE offer higher education institutions like the University of Sheffield?

CW: The problem is we can do **so many little things** at the moment on the CE, when we do our big development projects, we can send off our old carpet off to the company that makes new carpet and we can buyback eventually, where they make carpets from recycled carpets which is great **but the opportunities are so few and far between**. At the moment they are quite difficult to get involved in. for example there is a company called **Desso** that do carpets, they will take old carpet from us for recycling, the problem is we have to strip the building and store the old carpet somewhere because they won't take it until you have placed an order and they won't take it until they come to deliver the carpet. Where do we store all the old carpet for 10 months? **It is a bit impractical.** There is a logistics problem and the procurement route. When we do our procurement we are not specific with what we want. When we do our design and build, we just say we want carpet with recycled content or we want brown carpet similar to and we state a product. The company does not have to use what we stated. When I spoke about Crookesmoor building for example, we had specified in there that we wanted carpet with recycled content and I saw the site manager and told him I wanted to send all the old carpet to Desso, he said they won't place the order until the very last minute because they might change their mind, I said we asked you to do so and he say they can do what they want because the contract allows us to do so. **So it's quite difficult because you have to be very specific in the tender but some legislation does not allow us to be specific in the tender**. It becomes quite hard to even if you want to.

I think it is hard, especially when it is down to how businesses work. If you are going to send something to a company to be remade, they've got to be local, you have to store it. The whole waste management industry is not set up to help CE. Our waste contractor in some months doesn't make any money. The business doesn't make any profit. They are on the cusp all the time. Our general waste and recycling goes to them. They keep the recycling themselves and they send the general waste which does go to materials recovery facility for picking but some months because the market is so cyclical they make no profit. It makes it very difficult for businesses to operate. When you are selling and buying such material and remaking stuff, I imagine that is difficult too, some months things are going to be very expensive. **It has a**

knock-on effect on us. We pay money for recycling and it is cheaper than general waste but not significantly less.

Q: it would seem you have quite good interactions with the waste companies?

CW: Yes, our waste contractors, 8 years

Q: was there any specific reason behind the choice of the waste contractors, there seems to be many operators within the city region?

CW: when I wrote the tender I was quite keen on, while we have a number of constraints on campus about sorts of waste management one of them is we are quite long, we are not compact and do not have a lot of space so we need to have the waste picked up where it is generated because we cannot make it around very easily though we do have a recycling team that collects it up and we don't have lots of room for lots of bins so what we really need to do is to collect material in a mixed waste stream. It's not the favoured option. That's what we needed to do. I have lots of colleagues within the university that just don't care and I am not going to get all the materials in the recycling bins that I want. I needed to make sure I got all the value out of the general waste, so I didn't want energy recovery, I wanted it picked. The tender was mixed recycling for all materials plus general waste to be picked and the residual to energy recovery and Premier were the only company that could offer that service. Nothing was to travel more than 50 miles, keeping it local. We have a coffee cup project going on in the university to see if we could do something with the coffee cups and we've seen a couple of companies than can send the cups to Cumbria or Kent and I am not going to set up a scheme to do that because I can see no value in sending coffee cups that weigh 20kgs at a time all the way to those locations to be reprocessed when the carbon savings will be increased if they go for energy recovery down in Attercliffe. There is no environmental value, it might make us look like a committed environmental conscious organisation but it would be a front. **Environmental value vs Image issue.**

The coffee cups can be recycled but need a special process because they are coated with plastic that makes them waterproof. This is why we put them in the black bin in the university and not the blue recycling bin. Additionally the waste contractor would need to hire additional manpower to sort and pick them out if we did and they also need volume to make it worthwhile. They have huge vehicles that consume lots of fuel, materials recovery facility that costs millions of pounds and they have shifts. They need to get the throughput and that process to make money. They have three shifts a day so they've got to get the materials in, processed and sold and get the money. Volume and quality of product is very important. They also sell in one tonnes at the prevailing market price. They did a trial with the paper cups and what they found was that you need thousands of cups to make a tonne. It takes time and before you get the right amount, the cups would have started to rot because they are wet.

It is not a viable route to take. The best approach is to use reusable cups. People don't want to hear that. It's all about recycling. Going back to the waste hierarchy it is reuse first. Coffee cups are even making it on to party manifestos. Proposals of putting a 5p surcharge on coffee cups are being put out there. It may have worked on plastic bags but you know the bags were initially free and now you pay but it may not be that easy especially given the cups are not easy to carry. **It needs to be about reuse.** Maybe you rent a cup like a gas canister where you pay upfront cost and you take the cup back for a clean one next time. The quality of the coffee isn't affected because you get a clean cup every time, we need to consider or a deposit approach. **It is easy to throw away things in the West because it is easy**. This may be completely beside the point but in countries like Cuba, people keep things forever and fix them due to the economic situation. It's about promoting buying stuff for no apparent reason. An example is the incandescent light bulb and the cartels in America that came together and intentionally reduced the life span of the bulb to increase sales, encouraging waste in an economic system that is flawed.

Q: what do you think about planned obsolescence of many appliances? Is there any way to deal with this from a policy point of view?

CW: Because in this economic model we need to sell stuff to make money, people could still have jobs and an economy that works if people fix things. It doesn't have to be about making things and throwing things away. In the developed countries, there are landfills full of stuff. When we start to run out of resources, these landfills will start to get dug up for the valuable materials buried there. We might start seeing landfill mining for metals and precious resources. **The throwaway economy.**

Q: **there seems to be large number of computers and printers on campus, in the labs, diamond, IC, How do you manage them, what influences the choice when buying them?**

CW: The procurement team handles the purchase of these materials. You would have to speak to them. We have done work on printers on campus. Everyone used to have their own printer. We had a big project called my sustainable print. We got all the MFPS in. we did that and it was easier to manage. We had an estimated 3000 printers and all the consumables that go with that, left plugged in and incredibly expensive to run and moved to shared printing and it has offered us massive savings with lots of environmental benefits.

Q: When you buy these electronic products, you have to take into consideration the life span of the products right?

CW: I don't get involved in that. This is managed by CICS. We have framework agreements and they say what products they want us to buy. CICS recommend and you are not allowed to buy printers without their recommendation. Computers are devolved down to departments. Some organisations have a 5 year refresh. We don't really have that. We kind of sweat the assets. It also depends on how much money a department has. If a department has a lot of money, it can do that. It comes down to department wealth. Poorer departments tend to use their electric equipment for longer. CICS do have a refresh program for the student computers. They tend to do the refresh and pass on the old computers to less wealthy departments.

Q: What happens to these electronic products at the end of life?

CW: we have a recycling team consisting of 6 people. We have an online form and people in departments can fill saying I have a kettle, computer, fridge and the team collect and take the items to the recycling yard or secure store. Wastecare ltd recycling based in Leeds take the bulky stuff e.g. fridges, lab equipment and Aspire ltd take the smaller equipment. Prices have gone up for recycling partly because there are only two sites in the country licensed to recycle fridges because of the gases. Aspire are local based and are a social enterprise that refurbish stuff. They work with people who find employment difficult. The problem with electric equipment is that they are also on the edge of making money. This is the third company we have worked with. Two of them have folded. They wipe the data. Aspire get the equipment for free. Everything stays in the UK.

We have to move away from the idea that waste disposal should be free. It isn't free and it is a service. You've generated something that needs to be dealt with and there are costs involved in the collection, processing and proper disposal of the waste generated. In order for it to be free, they would have to be able to make a lot of money at the other end when they are selling it on the material for reuse and in a capitalist economy that is what is driving business. Too little involvement, oversight and regulation from the government in the waste management industry show a lack of commitment to more sustainable waste management.

Q: To what extent will new governmental policy and initiative encourage the move towards the Circular economy (CE)?

CW: it won't drive anything. Companies are only interested in profit. Businesses do not exist to service the environment, businesses exist to make money. There has to be financial opportunities for them to be there and the government needs to help them do that and provide the framework.

Q: would you be in favour of more government policies and intervention?

Businesses do not exist to service the environment; they exist to make profit (money). There has to be financial incentives to be there and the government needs to provide a framework.

Q: the university computers change over time, which generates a lot of waste at the end of life

It is important that waste is managed properly

Q: in the course of doing your job, are you in constant contact and collaboration with colleagues in procurement and energy officer?

There is a silent approach. You would think so but it is not the case but it should be. It would take someone to organise that.

Q: in the course of doing your job, what is the hardest part?

Getting people to do what you need them to do. Getting people to use the right bin, not chucking electric equipment into skips and that sort of stuff because people aren't that interested. You've got all these things that you could/should to be done but you can't make them happen because businesses are going out of business. Furniture is another major waste problem we have. We used to send our furniture to a company who were another social enterprise that worked with social offenders to refurbish and resell the furniture, they went bust and one of their supporters pulled and another company came in and also went bust because they could not make any money. I know all these possibilities but struggle to find a viable or option that isn't massively expensive. Or with the cups an option that does actually deliver an environment benefit instead of jumping on the bandwagon.

Q: what would make your job easier? Would it be more awareness?

Engagement would make it better but people are not interested. People are more interested in what they are having for tea or where their next holiday is. Environmental issues appear far removed. The last voting numbers were really low. People are not even interested in politics and voting now, and this does affect them instantaneously. It is really hard. Maybe policymakers should take decisions off the people like the European Union did with the light bulbs. You can't buy incandescent light bulbs anymore. You take away the choice from consumers. Marks and spencer and coops have done it. M&S only sell Fairtrade tea and coffee; coops only sell free-range eggs and Fairtrade coffee. Most consumers would go in and would choose over 0.05p and forget the ethics but if you don't give them the choice. Maybe the government needs to start making the bigger decisions that you can't trust the consumers to make perhaps.

Q: CE has been most successful in china, a planned economy (Top-down approach), would it be as successful in free market economies?

I keep talking about the economic model but the economic model is not conducive for circular economy and environment sustainability. They are pulling in different ways. We will never achieve genuine environmental sustainability and development when this economic model is pushing us down this direction. People have been talking about this for years and nothing has changed. It is probably because people are getting richer and benefiting from the status quo.

Q: in the transition to CE, who do you see leading the charge?

It is got to be government, changing the status quo. The politicians do what the people want or are the politicians in charge?

Q: Is there anything you would like to add?

It is difficult to stay positive, what difference do you really make?

Q: have you considered working with developing countries as partners for your electric equipment at end of life?

It is very difficult. The EU and the environment agency are quite strict about shipping waste. They have to be fully functional working order. You cannot ship rubbish or waste to other countries. The equipment gets checked upon leaving and arrival and it can be refused and the sender becomes liable. There are companies that do that. I just don't think the stuff we get rid of is valuable enough. We still get rid of old monitors but they are not good enough. We have so many hoops to jump through. I have been approached for student projects and would be happy to work with anyone. We have to be careful that we don't send stuff that should go for disposal and cause further health and environmental issues.

D-M, A- Limited, Sheffield. Social enterprise, WEEE refurbisher and recycler Stakeholder, 2pm SHEFFIELD, 14/06/2017 1HOUR 15mins (SE)

Can you give us a bit of background about yourself?

I am the ***General Manager and an associate director*** here at Aspire limited. Conflict of interest means I can't be a director and employee. I look after the day to day running of the business and the people. ***As a social enterprise***, I make sure the business matches the social outputs we need. We are no longer a funded charity. We are a self-sustaining fully commercial functioning enterprise. All of our core costs are met from the businesses we run. It is my role to keep it all together. We used to be fully funded homeless organisation. We used to part of a national franchise. We are one of two left. Oxford went down the fundraising route we decided to go the business route and we are fully in control of our own destiny. We can pretty much do what we want. I joined in 2005. We quickly decided to move away from the homeless pigeonhole as we kept being asked to work with different groups such as substance abuse, mental health issues, and physical disabilities. ***We now work with anyone classified as vulnerable or excluded.*** Teams change year to year. We could be working with people with autism. We started off offering packing services ranging different items such as goodie bags, clothes, tools etc. the main business is the ***WEEE recycling and computer refurbishment***. We are a licenced Microsoft registered refurbisher. We are licenced to refurbish redundant and unused computers and reload them with Microsoft software according to the agreement. We try and keep all our businesses local. We support local people and local economy. We encourage local businesses to donate WEEE to us because you find recycling companies advertising with a local number and they won't be local. We are truly local. We have gone further than south Yorkshire but we try to stay local as possible. We are a charity that supports local people and we encourage businesses to support us in that same social output.

How do you source the WEEE?

It is a mixture. We run a couple of contracts about collecting the items. It has to be tracked and recorded every step of the way. All the data-bearing assets i.e. hard drives, photocopiers, laptops, desktops, servers etc. have to be wiped or destroyed according to industry standards. We manage waste disposal for a few large clients such as the University of Sheffield. We offer free disposal service where companies and people can donate things to us. Some companies do not understand that just because an item is unwanted it is classified as waste, it isn't. The environment agency help determine what is waste or not through their waste guidelines. The environment agency states that anything that can be economically repaired or reused either for someone else or original purposes it is not classed as waste and can be freely donated to a community workshop or charity. We are both.

We are not limited to electronics and IT. Just like any other charity we will take anything. There are only a few items such as fridges and freezers, fluorescent tubes and the special biohazardous chemical material that we are not licensed to handle.

We don't have waste. For instance, if we decide a computer is too old for refurbishment or completely broken, we will break it down to its core components and try and sell them off if they have a value. We will try and offer the components to artists or someone who could make use of them. We deal with lots of children's charities and scrap organisations and give them stuff such as old keyboards and telephone that are used in play pods found in schools intended to create creative play. We deal with scrap stores where people tend to go to buy things for use in projects such as homemade greeting cards. We do trade in vintage electronics and items. We do a lot of business with a company called Bad Dog Designs which turns into fantastic clocks; steam punk etc. people buy Victorian items with modern style. According to our definition of waste, we have none. There is a use for almost everything people discard.

If you go down into further recycling, we send a lot of stuff to refinement centres. We destroy hard drives for example and on the back you have little pcb called the hard drive control card. It is full of precious metal. The refinement centre will grind it up and put it through various chemical processes and extract all the precious metals and turn them back to nuggets to be sold e.g. Mastermill, SIMS, and AWA Refiners in Essex.

Do you have dealings with other players in the industry?

Yes, you tend to find it is a closed sort of environment. You eventually get know who the main players area and what they do. Not only are we a charity and social enterprise doing WEEE recycling, we also do a lot of stuff other recycling companies do not get involved in.

What about the council?

We deal with the council. We are part of the Sheffield city councils Digital inclusion project which aims to provide affordable IT to people that are the furthest away from it. We are able to provide by referral a full desktop internet ready for as low as £20 thanks to support from local businesses giving us their old items and our Microsoft licence.

Are you also regulated?

Yes we are regulated by the Environment Agency. We have a license. We are inspected and the licence is granted every three years. There is a cost involved. We have to pay for the licence. We do not get it for free. We get the waste carriers licence for free because we are a charity. In our case the waste licence is the T11 which allows us to process up to 100 tonnes of equipment for recycling and refurbishment every year. We are still a small organisation punching well above our weight in terms of the business activity that goes on the amount people we help. In terms of waste processing we are still well under the 100 tonnes per year.

What is the main obstacle to WEEE recycling and refurbishment you face?

The biggest challenge is ***Data issues. People don't understand data.*** They are either too over the top or if the other way, they are too lax. It is relatively easy to protect your data. When dealing with people you find people have little knowledge or interest in technology and you field all sorts of questions such as do you pick it up in an armoured car? When people donate laptops to us, some feel that that laptop will always have their information on it. They don't understand that the data is stored on a little flat metal disc or SSD and separating it from the main body of the laptop is relatively easy. It is a challenge to let people know **(enlightening)** what data is, how it is stored, destroyed, how easy we destroy data and the protection and protocols we have in place to prevent anyone getting their hands on the data. Important information is more likely to be gained from employee social media posts than an old office computer.

Would receiving already data erased equipment make it easier?

Yes, it would. I now like to give people options. People can destroy their own data or have us do it free of charge.

From the business perspective, in the recycling side, it is a commodity and like most other commodities, prices can go high and low **(the cyclical nature of the market).** It causes serious pressure when prices are depressed. It happened 2 years ago when china dumped a lot of metal. It is why we have other businesses. Some recycling companies only recycle. We are fortunate to have the packing business, the shop and online store, goods recycling to hedge our risk and exposure to price fluctuations. The good thing about the packing and recycling team is that they are interchangeable. Joining our team doesn't even need to speak English. Everyone can follow simple packing and recycling instructions.

How would you define CE?

CE is a recycling symbol, reduce, reuse and recycle. For me it is about extending the life of redundant products **as well as reinvesting in the local economy**. We are so involved in recycling side of business with local people we can see everything being reinvested in the local economy; we can see the local goods being donated by local businesses giving it a new lease of life, helping disadvantaged people.

What would make your work easier?

From the social aspect, I think the policy makers ought to ***make it easier for us to work with people with issues and particularly people on benefits.*** The current system doesn't make it easy for them to get back into work with charities or social enterprises like ours. There should be a national program to help people. It would have to be a voluntary process, not forcing people to do what they don't want.

I can't say anything about the Environment Agency because they were excellent and gave us sound advice. The Environment Agency website is complex and I would like to see it simplified and with more tools and resources. I would like to see the admin of waste processes also simplified. I know why they are doing it. ***There is a lot of bureaucracy.*** I think there should be schemes ***whereby companies find it easy to donate to charities***; a kind of implementing the waste hierarchy in the options provided to companies.

Do you think things will change after Brexit?

Probably ***not***, it would be nice if things became less bureaucratic but I don't think so.

If the transition from LE to CE is to become a success, what/who in your opinion will be responsible in taking the initiatives forward? (Private/public sector?)

I think there is no better way of getting people to reuses and recycling than ***to incentivise***. In lots of other countries throughout Europe and south East Asia, you have lots of different incentives encouraging people to recycle. You get money for bottles and plastics. In a particular country they have vending machines for recycling plastic bottles and it gives you some money. I used to remember as a child, we used to have soda bottles and you would get £0.10 for returning/taking back the bottle in store. At the moment there are no such initiatives. At the moment you have councils asking people to recycle but they don't see any reduction in bills. The councils could establish its own recycling centre thereby also creating jobs.

Does the Sheffield council not have recycling centres?

They do but they are never open and when they are, the queues are so long. They don't make it easy for people. You don't always have to incentivise it with money.

It is everyone's responsibility but someone has to give direction, point people in the right way. It starts at the top but it doesn't have to end there. **Recycling is dare I say lucrative** and there is good money to be made from recycling and reusing products. **The authorities have seemed to miss that.** People generally do want to recycle. We don't just take electronics but anything else that can be reused and redistributed such as toys. We are now an alternative to local recycle centres. We are looking to open one Sunday a month to handle goods.

In Sheffield, they have not done so well on recycling but on the refuse side the company Veolia built a new ***Energy reclamation centre*** near the train station which I approve of. Anything in the black bin bag gets burnt to produce heat and power for two hundred thousand homes. It is not recycling in the sense of the word which most people understand but it is. It is changing one thing into another useful thing. There are a couple of groups against the incinerator complaining about smells and particles but I think it is the top flats around the area. There is always going to be waste and traditionally it was landfill but not so much these days. Energy reclamation offers an alternative.

Can the circular economy work in a free market economy (recalling that all the successful examples - i.e., China - seem to come from centrally planned economies)? Is there a way to "force" markets to converge towards these objectives?

I think there will always be an economic case for recycling. It is just that people haven't found it yet, choose to ignore it or have always done something a certain way and are resistant to doing it a different way. Being in this industry I know and see the value of recycling. I think everyone is stumbling in the dark with no direction where to go. ***China is pointing people in the right direction*** and I ***don't think it would need too much work***. Maybe a government minister, department, local authorities, or even academics could kick-start it off. I don't know. As someone in this industry I will always look for a benefit/value on the recycling side of things. You have to look for it. There are a lot of people now doing it. You just have to look out there e.g. in Ghana they were making air-conditioning with plastic bottles.

What are your thoughts on Planned obsolescence?

It can be true. I am not a fan of Planned obsolescence. The thing about technology is something else termed ***"circumstantial obsolescence".*** As technology improves, things get faster. Do you want to be the one left behind? It is about inclusion and exclusion. Technology moves on. The people that don't catch up are excluded. They can't play the latest games. They can't see the latest movies on the VR headset. There are vast graveyards of old airplanes around the world because of new technology.

What can be done about Planned obsolescence?

It is progress. You could make a pair of socks that last three years but it's a pair of socks. It is roughly the same as it was hundreds of years ago. Other things such as laptops and computers will always move on and develop. If you were choosing a car, new phone or laptop, you would probably do more research into it. One question you always ask is how fast is it?

Is there anything you would like to add?

Reuse is understood by people we deal with. A lot of the donations we get are from people who are already quite clued up about avoiding landfill and someone benefiting from the product.

The industry is ***always evolving***. You have to anticipate what is coming. It can be quite ***changeable***. What is the the next big thing, the next piece of legislation to humper or assist your business. You have to have one eye on the future, get the pulse of where the industry is going or you get left behind quite quickly.

INTERVIEW WITH D-R-T, LECTURER IN STEELMAKING, (AC)

0:00

Why does BOF still account for a higher % of global production?

The largest producers use this method.it is also about volume and steel type.

BF-BOF or EAF?

EAF has been growing in the US, Middle East because of abundance of DRI and affordable natural gas. The ratio is 80-90% scrap: 10-20% DRI. Pig iron can be fed into the EAF.

BOF in china could be attributed to coal reserves in the past as well as economies of scale associated with BOF to meet china's demand for simple steel products for infrastructure.

Quality and chemistry of desired steel determines which route of steelmaking is chosen. Contaminants such as tin and copper are high in EAF but can be diluted Using DRI, especially in the case of the US.

Each route is important in steelmaking and improvements are needed in both to reduce material and energy use as well by-products and waste. There aren't much appreciable differences in the production phase. You have to factor in time and volume that can produced at a time.

If you go to certain places in the world, you will see a mix of let us say 90% scrap and 10% DRI. If you go to other parts you will see it differently say 80%. A lot of it is down to the availability of natural gas. In the UK it is a 100% scrap. In the US and countries in the Middle East where there is an abundance of natural gas, DRI production is cheap. We don't have a DRI plant in the UK, We are forced to use virtually a 100% scrap.

It is very important to make a distinction between waste and by-products. What are the potential reuse options of by-products? EAF dust is reused in the process.

Waste from steel production is in the form of solid waste and gas. Solid waste in the form of slag

Is it difficult to source metal waste scrap?

It is not. It is however difficult to source quality scrap. That is the big difference. Steel scrap in the UK is at a surplus. A lot of it is exported to countries like china. What is important is *the right quality scrap* and its usability.

How much scrap is lost to landfill, incineration?

I don’t know.

Is the metal scrap availability impacted by the surplus export?

The feeling at the moment is that there is enough and the surplus is then sold off elsewhere. You have simple chemistry steel scrap that is easy to melt and produce something else. If you have very complex chemistry, it becomes much more difficult. You may need additives to remove impurities and in some cases it becomes impossible.

If we take automotive steel as an example, generally that is quite simple grade, mostly iron quite easy to produce using this technique. If you try to recycle it, you get a lot of contaminants in there especially elements like copper and tin. If we remove them but they are difficult to remove. One way is to dilute them with DRI but the uk doesn’t have any dri. There are virtually some grades that cannot be produced using the recycling route.

Despite the environmental friendliness of the recycling route, it would seem that the BF route remains readily important, would you agree?

At the moment in the uk it is very difficult to produce some of the steel grades via the EAF Route. In the US, they can produce automotive steel using DRi because they can use it to dilute the contaminants so you end up with the right chemistry. In the uk it is very difficult ot produce certain grades using recycling route and that is one of the biggest challenges.

Everything is interlinked. If you change one thing you will need to change the other. There are generally good reasons why one thing happens in a particular way and one in another. There are financial technological, historical and scientific reasons why things have to happen the way they are. It is very difficult to suddenly start producing a product traditionally produced via BF through EAF and vice versa.

8:34 one of the biggest challenges facing the UK Steel industry is the energy crisis. It is difficult to compete. The UK is focused on value added products such as nuclear steels, aerospace steel, power generation steels complex steels that is difficult to produce using the EAF route. It is not like the UK is the only place to produce these steel but the ones produced in the UK are the best in the market. The industry has to be careful not to focus on only the niche steel otherwise it will become very small. The UK still produces rail track, plates. It is not as if the uk has forgotten this. There has been a focus on maintaining the production of complex value added advanced steel. UK Steel is good place to start looking for information. There are hundreds of small steel producers in the UK who on their own may seem insignificant but put together are quite important. UK steel represents mainly the big players.

In Sheffield besides the major companies such as Tata, Forgemasters and Outokumpu, there are still small companies producing very-specialised steel.

13:55- do you think different policy could improve steel industry performance? (Need for more/less legislation, consumer awareness, incentives etc.)

If energy became cheaper such as electricity prices, cost of labour, environmental and safety regulations are factors affecting the UK steel industry.

15:50-Where are the raw materials (Iron, coal, steel scrap, electricity, limestone) sourced?

In the UK, Iron ore and coal are imported while limestone and electricity are sourced domestically.

China is currently producing a surplus of steel not just to sell abroad but also at the domestic level. Even though most of the steel is produced via the BF route, they will soon be able to produce via the EAF due to increased steel scrap domestically. The worldwide availability of scrap may soon be different. China could become an exporter.

Does long use life e.g. construction steel use in buildings affect recyclability of steel?

Yes, I guess it does, but only if scrap is in short supply. Is the scrap useable?

19:59- From your experience what can be done to promote efficiency, reduce possible leakages and circular economy in the steel production?

- Product design: changing steel chemistry to get steel that is stronger and lasts longer.
- Cleaner production: using less raw materials in the process while achieving the same properties,
- Looking at alternatives to BF technology.
- Understanding how you could use biomass at certain points in the steel production route say instead of 100% coke, can you use 90% coke and 10% biomass?
- Everywhere trying to minimise by-products and waste that come from each stage of the process. If you don’t produce any by-products and waste, then you don’t have to worry about what to do with them.

There are a lot of things going on at the same time. Some of it is metallurgical, process, or technological.

23:32-How much would it cost (input) is needed to produce steel via the two routes?

This is very difficult to answer. It depends on how you look at it and the steel specification you are producing. It would also differ from plant to plant. It is easier to compare energy requirements rather than other inputs such as cost. It also depends on how you do the calculations and what life cycle model you use. You need to look at the whole process. There will be different energy requirements for primary steel than recycled steel and that will affect the cost.

Is the industry affected by scrap prices and sources?

Yes. Steel scrap in the UK is at a surplus, a lot of it is exported to countries like china. What is important is the right quality scrap and its usability. UK steel has been focusing on advanced steel such as valued added steel, nuclear steel, aerospace steel applications. UK is around 80:20 in terms of BOF: EAF

LCA: unaccepted but good to document it.

References

Look at the works of Julian Allwood, Jean-Pierre Birat, steeluniversity.org

https://www.youtube.com/watch?v=g1yUFUL-_AI

Links

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Interview with M- R (AC2)

Introduction

Environmental sciences background, chemical sciences and LCA 2006 PhD, more than11 Years of experience, senior research fellow, Mech Eng & mathematical sciences, XX University, UK

Q: How do you define circular economy? (In an ideal world, what would the economy and society look like if it was based on a circular economy?) Would a circular economy create a more sustainable society? Why/ why not?

It is an ultimate goal to be achieved. Nothing can really be circular. There are some inefficiencies, and openness to the circle. Material and energy degrade, they have to be replenished. Any notion of CE is utopian really. In principle, the idea would be to mimic what ecosystems do in nature, which is to reuse and recycle material and resources as much as possible within the system rather than keep extracting from the surrounding environment and dumping the waste at the end of life. The idea is to find ways of different parts, economic sectors, industries to be linked in such a way so that the inputs of one sector are the output or leftover bits of another sector eventually closing the loop and keep using the materials over and over again as much as possible.

Whether or not it can be achieved in the real world is debatable. There will always be in a sense some inefficiencies. It is a good goal to have. There are quite some roads to go still.

In an Ideal world, the economy would have to incorporate many factors that are currently not accounted for to the extent that they ought to be. I am referring to all those environmental externalities that not priced, therefore not taking into account by the current economic paradigm resulting in the undervaluing many natural resources, ecosystem services and market distortions that lead to some linear chain of processes that extract resources and produce waste being more affordable and more economically advantageous than others that incorporate more of a CE concept that end up being more expensive and hence less advisable from a conventional economic point of view because the economy does not take into account the side effects of this way of acting. In an ideal world the economy would have to incorporate a lot of biophysical knowledge, there ought to be a paradigm-shift, to put the environment in a more central position and recognise that the economy is supported by environmental resources and not the other way around. This should naturally lead to CE. It should not be forced but be the natural outcome of restructuring of the economic theory of value.

In reality, things take time; change is always slow, sometimes too slow. The economy will start to incorporate elements of CE and it is already happening either through legislation or a series economic incentive, we might inch our way closer to this goal and over time, it may become more viable and affordable, to close more loops, step up clusters, more by-products are used rather than dumped. It will be a gradual process, slow, maybe ineffective at times. There has been some change and will be more.

Q Is CE Desirable?

Yes, there is a lot of unnecessary waste generated

Q Is CE Achievable?

To a limited extent-not fully because the current economic system economic does not intrinsically put value on many ecosystem services seen as outside the market. This is a misguided view. Nothing is truly independent of anything else. As soon as you produce, there is an impact on the environment, there is some waste, and then indirectly that will end up affecting the economy in ways that are so indirect and not accounted for leading to the concept of economic externalities. This refers to any costs that are not factored in the actual cost or price of a product. If all these externalities were included in the accounting then automatically a more circular use of resources would result in cheaper products, more affordable. It would be adopted automatically. But it isn't because **all these indirect chain of effects are artificially left out of conventional economic thought.**

CE IMPLEMENTATION

In your opinion, how eager are stakeholders in the metal industry to embrace the circular economy CE as part of its overall sustainability agenda?

I wouldn't say they are eager. I do not have that many connections to the metal industry to be honest. From what I knew, what I have read, observed and understood, the metal industry begrudgingly follow where, what is dictated by current legislation. I don't see much eagerness. It is more like we will do what we have to. There are exceptions, because of incentives, legislation or added taxes, as soon as there is a window of opportunity for something to be made cheaper or with less expenditure and that way happens to be in line with CE, and then of course the industry would be eager. The metal industry is doing better than other industries because of the quality of the metals. The industry only jumps on something offering economic incentive. There are many opportunities for economies of scale, recycling processes to contribute to both economic affordability and environmental benefits.

Another driver of CE in some specific sub-sectors is the ultimate availability of some metal. In most cases, the metals are finite but some particularly are being depleted at an alarming first rate. There is an additional drive towards a more circular use of these metals because of concerns of availability, sustainability in the medium-long term of the whole a sector. Many metals used in mobile devices, computers, flat screens, inosme cases, it is very important to recycle even if it is not in the short term cheaper, it is still looked at otherwise whole sectors could be out of business.

What are the challenges faced in the transitioning to circular economy CE?

I think it is technical. Achieving the right grade of purity in the recycled metals so they can be used in the same application maybe a challenge. One challenge is economics. It has to be affordable. They apply to other sectors. Some materials such as plastics degrade over each recycling cycle and its affects the physical characteristics of the material and as such there is a limited number of times a material can be recycled and still be of good enough quality in some applications. This obviously put a limit to the ultimate circularity of that part of the economy whereas with metals industry, this limit is pushed back a lot at least in principle you continue recycling a metal almost indefinitely. These are the kind of issues that would vary in cross sector applicability.

What opportunities would circular economy CE in the metal industry offer the various stakeholders?

Each stakeholder wants to make money out of CE. Each stakeholder is mainly concerned with their own benefits. There will be different incentives of course as well as different benefits. If you consider the public at large as a stakeholder, then one of the benefits would be the reduction of environmental impacts, the reduction of unsustainability in the long term etc. if you speak to individual stakeholders in the sector it would probably be about more margins or competitive edge.

What role do you see private and public sector having in going towards a more circular society in the metal industry?

I think the public sector should be a bit more far-sighted, and set goals then the private would follow suit. This doesn’t necessarily happen all the time.

Do you think concerted and collaborative effort, as well as intensive stakeholder engagement will help the move towards a holistic Circular economy (CE) in the metal industry?

The questions are bit general. If you could give a more specific question, I would give a more specific answer but in general it is always good to have discussions to keep the discussion going, to have different stakeholders interact.

Can the circular economy in the metal industry work in a free market economy (recalling that all the successful examples - i.e., China - seem to come from centrally planned economies)? is there a way to "force" markets to converge towards these objectives?

I think the fundamental problem of the market economy again I repeat myself is that the market as it stands doesn't take into account many side effects of economic activities such as environmental effects and ultimately effects. The free market is a wonderful in some respects but always pushes to making stuff cheaply as possible. In some cases it does push in the right direction and does contribute to a drive towards CE but in some cases it might be counter-productive. It is just so easy to keep plundering the planet and resources and dumping everything. There will be loop holes. **So yes in principle there is no reason why it wouldn't work** but more often than not it will not work as well as it could because there will be loop holes and places where there isn't legislation to regulate and incentivise one pattern over another.

China does come to mind. Obviously every time you can make something more cheaply, by reusing resources rather than extracting new ones, definitely that is one instance in which a free market may actually help but again this fundamental issue with the economy makes it harder to make the case for CE over LE.

Legislation is probably the only way to make markets to converge. Agreements between different countries to stick to certain standards and to enforce some targets on recycled content, a cap on CO_2 emissions per functional unit of material etc. some form of legislative effort is required otherwise it will be easy to find loop holes. It could be EU or even WTO.

Do you think Europe has adopted a reductionist view of Circular economy (just focused on waste recycling, but not involving any rethink of how the economy works)?

YES to some extent, but not only Europe but the world. Europe is doing good compared to the world in terms of moving towards a CE. Even in Europe there has been a **lot of focus on waste recycling** as has been correctly pointed out but not enough rethinking of how the economy works and how to link different industry sectors so as to effectively make use of the by-products and waste flows in a more efficient way. It is easier to set waste recycling targets than to find ways to link different independent sectors to link to one another, to work together, collaboratively towards a common goal. It is understandable why there has been this reductionist view.

In your opinion, what policy instruments do you think would be necessary for the drive towards Circular economy (CE)?

The carrot and stick approach always works. On one hand more stringent regulation and on the other more widespread incentives, economic incentives. In tandem, these two would be effective. There are not the only ones.

If the transition from LE to CE is to become a success, what/who in your opinion will be responsible in taking the initiatives forward? (Private/public sector?)

Both the public and private sector have a role to play. Governance and legislation have an important role to play on the other hand the private sector can also be proactive in ways that appeal to the public for example active advertising of a product that is greener in terms of being making use of recycled components and materials and being more in line with the CE concept. That can be more appealing to the public if the public is sensitive enough to that sort of argument and if the product doesn't end up being more expensive. If the private sector can find ways to not necessarily reduce the price of a product but keep it the same while increasing the circularity of material and energy usage, I think this could be something that could be advertised as a benefit for fighting for the environment and so beyond what is currently required by legislation, the private sector could be an active force in this drive to CE. So both but in the absence of stringent legislation and incentive schemes, you cannot expect the private sector to just do all the work.

Is there anything you would like to add?

I think something missing in this long list of questions is this concept that I keep referring back to. There has to be **a more open recognition** of the fact that the current economic paradigm or thinking or mind-set fundamentally does not take in to proper account any of the indirect side effects of economic activities in terms of loosely speaking environmental impacts. Economics as a discipline would do well to incorporate more and more biophysical elements into economic curriculum and academia, to training programmes for present and future economists so as to drive home this concept. Looking at the world from a purely economic perspective misses a lot of things, a lot of important aspects. You can't just wait for things to become cheap enough to do them. Sometimes you have to be proactive. To do this, you have bring together these sometimes diverging views would be to incorporate these non-monetised effects into the economy e.g. carbon tax, ways in which a product could be made accountable for the indirect damage it wreaks on the environment and if that were to happen, automatically it would become much more economically viable to recycle more, to adopt a more circular pattern.

Would this economic paradigm shift not affect livelihoods given the lock-in?

I think there is a misconception. It might in the very short term but ultimately I think it is the other way around. Because if the current economic approach and way of thinking keeps neglecting these indirect effects, the bill will get much steeper and we will get to the point where we won't be able to afford fixing all the damage. We are running out of time in terms of incorporating these externalities into the economy. If we don't, ultimately this will come back to bites us because what is the economic cost of remediating the damage? What is the economic cost of mitigating the effects of climate change? It is going to be huge. That will affect the livelihoods of more people much more than some additional cost imposed by a more inclusive economic paradigm in my opinion. I think it is a matter of short term benefits vs long term benefits and more often than not policy makers and the economists etc. tend to be more focused on short term benefits. Obviously everyone wants prices to be fall or stay as they are in the short term because otherwise everyone is complaining and there will be higher costs of living. No one is giving enough thought on the long term effects of business as usual and not taking into account the long term impacts.

It is about time to rethink our economic paradigm. That would be about be the bottom line and is more important than CE per se**. CE should be the natural outcome of a rethinking** of the current economic paradigm rather than something that we can find ways to force people and industry to adopt because otherwise it will just a patch and won't be enough.

Speaking to a policy maker, the issue of the on political system not being particularly favourable to CE in terms of short term tenures was brought up, what is your take?

I sympathise with policy makers, I just think they are kind of locked in. they are accountable to the people and the people don't realise what the ultimate. There is this loop whereby people demand better conditions in the short term and policy makers have to deliver those. It is a vicious circle because you keep standing the same place. There is no easy way out of it. The current efforts towards CE, in EU are a good step forward. I fear they may not be enough because they are not radical enough. We have to be realistic in our objectives. The more we talk about it, hopefully more people will start to pay attention. There isn't any indication that current political leaders are particularly willing to heed this advice e.g. Trump, the conservative government.

Interview with J- P, Sheffield, NGO Stakeholder

Can you give us a bit of background about yourself?

Part time campaign worker: lead some campaigns, such as climate jobs, talk a lot to trade unions, city council, what programs they have, encourage them to do programs like insulating homes helping health as well climate change thereby also promoting social benefits. Climate is not an environmental issue but an economic and social issue. It is going to impact our economy and society. I am interested in trade Unions in heavy industry, how do we change these industries without workers not losing their jobs. This region has been affected especially with the collapse of mining in the region. It was bad, and makes people resistant to thinking about a low carbon economy, people are nervous and hesitant. There is a booklet called one million jobs outlining what to do and benefits of climate change. In the UK, we don't believe in planning, we believe in markets and we believe the markets will solve the problems out. The market solves the problem by moving jobs (steelmaking) to china and making people unemployed here or worse. You are left with jobs that have little security and pay or zero hours contract working in a call centre unlike the old jobs with pensions and decent pay. 3 years. I was a volunteer before it became SCA. I was sending out newsletters. We started working with different organisations such as faith groups and trade unions. We got better at thinking outside the box and finding people who share our thoughts and concerns. There is the popes' statement and Islamic statement on climate change which are powerful.

For instance we spoke to the cabinet member on transport and infrastructure, if they manage to have a transport policy that gets more people to leave their cars at home and take the tram or buses, bicycle, they get benefits for the climate and less emissions and congestion and benefits for air quality and people doing more active travel because of problems of obesity and sedentary lifestyles getting people to walk or cycle is a very way to do that. It is a win-win-win. It is a win for the climate, health, quality of life and the economy. If they take the bus instead of buying petrol, the fares they pay stay within the local economy in the form the bus driver's wages. The drivers are local and the people who mend and look after the buses.

Do you work with other groups such as yourselves?

We are part of a group called the climate coalition nationally with members like RSPB, friends of the earth, trade union and churches. We are also part of the campaign against CC. We try to make links locally. We hold events locally and getting to know people. We are always building a network that is getting bigger and bigger. We have worked with over a 100 organisations over the years. A lot of it is based on relationships. We might collaborate. For instance we lobbied MPs last year with CAFOD which is a charity.

During the CC talk we both attended on Friday, there was a call for an economic paradigm shift, moving away from GDP, what is your take?

That is the crazy thing about GDP. You basically add up what people are doing, any kind of work. It can be food production as well as dealing with food waste, the more food waste you have the more the economy is growing. It could be selling cars and dealing with car crashes. The more crashes the more the economy grows. They are these really stupid ideas and some economists have looked at how you measure real value in the economy, social economic and environmental value. Herman Daly has studied this. Instead of aggregating the good and bad things as with GDP, you actually look at the benefits. They don't teach this in the economic courses, only the old theories of value. Tim Jackson's book "prosperity without growth" is a good read. He is coming in October in collaboration with the Grantham Centre. We are also part of zero carbon Yorkshire.

What do you think of CE?

I think the simplest there is a short animated video called the story of stuff. It shows how an economy which is just churning stuff out and creating waste and how bad that is for the economy and environment. I think the CE is the opposite of that. It is the fact that whatever you make, you don't call it waste. You have to think about everything you make in terms of how it is going to be used in the next bit. It is an idea that comes up in something called "Perma-culture". It uses ideas of the natural world and how nature recycles. Organic materials compost into soil and so you don't have to clear dead leaves.

Is CE possible?

I think it's necessary, at least to a great degree. Tim Jackson argues that you would need to increase the carbon intensity of everything or every dollar by about hundred and thirty times to get the track of being sustainable. The only way you can do that is with something like the CE where you are rethinking your processes more than just making stuff and ignoring the side-effects. A good example is the carpet company that rents you out carpets instead of selling it to you and the end of life they recycle it into new carpets. A steady waste stream is important for CE. We used to have deposits on bottles and you got your deposit after returning it. Milk used to be in bottles and the bottles were reused. Now we are using plastic. Plastic is lighter. The milk is transported further.

CE is possible. I've seen it. I grew up with the milk man. I see so much waste. It really shocks me the way we do things. With many things in life you can't buy a good one anymore. I have rucksack and they are always falling apart and I through them away regularly and I have get a new one. Once upon a time I would have had one that would around 5 years. Nowadays they last less a few months. The products might be cheaper but not effective.

What do you think of planned obsolescence?

I think is a bad thing and would do away with it. People have houses lots of stuff. Some even need storage to keep all the stuff. We have a relationship with stuff. People love to have new stuff while at the same time some wouldn't mind keeping stuff longer. Doing away with planned obsolescence might help.

What do you think are the challenges faced in a transitioning to CE?

I think it depends on which frame you are looking at it from. Bigger change is possible. The best example we use with climate change is 1939 World War II and overnight completely transformed their industry from making cars to military planes and equipment. It had to be done and so they did it.

If you look at a planned economy instead of neo-liberal economy, different things are possible. I am not saying but if things get bad enough and need changing immediately, we might lose our ideological fixation that we have to have things done by the private companies for instance. In the present labour manifesto for the election, they are advocating for the nationalisation of railways and may probably reduce waste. You end up with different companies competing with each other to do the same thing, duplication of structures, for the infrastructure you have a central organising company and infrastructure contractors and you have to have the same kind of staff in parallel in the two companies, one of them actually has to do the job, design the work and the other has to check that its designed properly because they are paying for it. That is actually waste, duplication and material. The public pays more each year for train fares and the taxpayers pays a lot of the essential tings of railways and a lot goes to profit of the private companies. It's not necessarily about waste but about how things are owned or regulated. For example, to have an effective renewable energy system, you need to have public ownership either at the national, local, or municipal scale; private companies do not have the incentives to do it. It needs to be linked to getting people to use less energy and private companies do not have the incentive to make that happen.it always comes back to economics and politics.

How would you promote CE in metals within Sheffield region?

I used to be involved in a group called Sheffield first environment partnership back before 2010, comprising different boards on the environment, economy etc. We had people from different industries coming together to decide how to tackle things. It was very difficult to get on the economic agenda and talk about low carbon. We would propose ideas such as carbon budgets, prosperity without growth. It would always meet a blank. I don't know enough about people doing business within the steel industry and what makes them tick. I meet a few of them sometimes. In terms of the wider players, now you have the **Sheffield city region and local enterprise partnership (LEP) that would the kind of place to get these ideas across and understood**. You also have the local chamber of commerce which represents smaller businesses. The LEP agenda doesn't seem to be very informed by ideas or research, forward thinking or by getting research done, or making the most of what is inside the universities. There is a real divide about how people think. The LEP keep thinking in the same way.

Which definition appeals more to you from the list?

The one that made reference to keeping goods at their highest utility for longer. One thing that I have noticed from the conversations I have had about the economy and environment has been getting people to move away from the idea of growth. This is an in depth thinking. There is almost **a sort of emotional attachment to growth**. A lot of our thinking is quite metaphorically based. So when we see a graph going up, it makes us feel good. The fact that growth is this thing that grows feels naturally good.

In a transition to a CE, who leads?

I think it would **probably need to be three things**. **Universities a**nd people giving t**hought leadership**, **businesses** who have some of the most go ahead in this area who have set up businesses and just gone ahead and done it, and then if you want to change how the economy works, you got to have **accountability** that the **government** provides through the democratic processes. You've got to have a way of linking that to people. We currently have a very thin connection between us and how things are made and it is really just about us paying for goods and services. It is fascinating when you see things repaired or for example composting seeing stuff regenerate thru natural processes. I have hope for CE The transition needs to include everybody, make us feel less alienated from the economy.

Can CE work in a free market economy?

The free market means different things. I think it's gone too far. I think some things need to be in public ownership such as the railways, the national grid. Some things made sense to be controlled by public**. I am a mixed economy person**. There are strengths to the free market Promoting innovation and ideas are a good thing, while you need regulation to make sure doing broadly the right things. It is not all about owning everything. I didn't know about the Chinese CE and it is good.

Germany is doing better for example with standards for components. Sweden is doing it not by being less neo-liberal but by not being afraid to regulate and have democratic control over certain things.

Do you think Europe has taken a reductionist view?

I really don't know much about that. I am only vaguely aware of the Europe taking up a CE package.

It is argued that the European view is this way because it is easy to measure achievements in recycling waste, and easier to coordinate, would you like to comment?

It is a shame because it is narrowing the scope. It is interesting. It reminds me of carbon footprints of things. It is much easier to measure emissions within borders but that starts to have unintended consequences because we think it is a good thing when we move all the steelmaking to china. It is still producing the same carbon footprint just somewhere else. When I was studying carbon footprints a lot of the references were on china.

Is there something you would like to add?

There was a Sheffield city region vision document launched in February. The University of Sheffield, Sheffield Hallam University, and the NHS Trust were all involved. It was led by Professor Heather Campbell. It is a 25 year vision for the region looking at economic and social outcomes. The document doesn't mention climate change once. We've written a response to it. It is not doing a great deal on environmental outcome by not mentioning climate change.

One of the issues problems in Sheffield is that many of the big players come from the steel and heavy manufacturing industries and their main concern is the price of energy and not thinking about CE and CC.

Interview with L-B, Former head of sustainability xxx steel company, UK,

Post-Industry Academic and expert Stakeholder, (PIE)

108mins, 3pm Diamond building, 16/02/2017

Can you give us a bit of background about yourself?

I ran an environmental research department for 15 years in Tata steel with over 50 people at its peak covering all environmental disciplines; water, land, air, waste, LCA sustainability, analytic chemistry, measurement on site and in labs for quality standards etc.

How would you define CE?

I am familiar with the EMF definition emphasising restoration and regeneration was at a British standards meeting for 8001 and we were looking at definitions. They said the CE is a business model which wasn't very good. They later on decided to use the one with restoration and regeneration. I like the part about longer life. I think most definitions struggle a little bit. In my mind CE I don't know if it's an industrial economy. The Chinese 11th plan definition starts off well. It assumes the CE is defined at the end of life but you ought to be designing it for long life as well. I don't know if CE is a model. CE could be defined as one in which the production and consumption of resources are decoupled from economic growth by the control and efficient use of resources.

What role do you see private and public sector having in the move towards a more circular economy?

They've all (both) got to work. **The private sector tends to be driven by its own economics and cost savings.** It almost goes without saying that resource efficiency of manufacturing for example usually means improvement in circularity or reduction in resource use. They are driven to produce more things because the more they produce the more money they make per unit so the private sector want to be high efficiency as well as high turnover so the question is can you steer them towards having products that themselves can be circular? If you think about computers phones etc., **invariably they are designed with a redundancy period.** A few **companies like HP** have decided they now agree with the idea of repair and fixing so they tend to standardise the size of laptops. There is an incentive for private companies to save money but they need to change their offering so their products are more life cycle or resource efficient. There is the tendency to offer more services a good example is interflow which is a company that makes carpet tiles and takes them back for recycling. They are selling a covered floor area instead of the carpet. They have some good designs. **New service models such as this are a feature.** There are problems with service models. The automotive industry has gone down this route where they lease out cars instead of selling them out rightly such as a four year contract per month. The residual value of the vehicle remains the property of the leasing party. Whether this reduces car production I don’t know. It might stimulate more efficient vehicles because they would be taking back less efficient vehicles than the current new models so and it could incentivise a more regenerative and restorative design from the beginning. They might start designing the cars so that when they come back at the end of the lease, they’ll do something with it. It would be good for electric vehicles because the batteries are the problem. I heard an interesting story, a colleague of mine bought a Renault and wanted to sell it but apparently the battery still belonged to Renault’s battery supplier so it came as a shock. Luckily he is an expert and accused them of misspelling the car to him and so Renault ended up paying him. **The issue of ownership is quiet complicated**. Who owns what where? For example, in the University of Sheffield, (access session). let us say a service provider provides the windows for this building and The University of Sheffield went into liquidation and the window provider is not getting any return because it, so think they can come in take back their windows but they cant. The liquidator would say if you do that we can’t sell this building. This shows how complex the issue of ownership is.

The public sector e.g. the NHS have the same incentives for improve costs, they are not selling things. There is a massive role for the public sector because they could reduce costs due to resource and energy efficiency. There needs to be **good collaboration** between the two for CE to be effective. There is a risk for the private sector of selling less stuff while the public sector needs to **incentivisation.** The **private sector has a large role** because they provide things.

Is there a need for new skill sets in order to move towards a CE?

Yes. For example, a designer needs to think about durability, life cycle, life extension. There is also a need for smart new business models. The carpet company example is good one. B&Q tried a business model and failed. Uber and its model has a potential for a shared society (shared economy). E.g. hiring a drill from B&Q and returning it after use. The question is in life cycle terms would be the vehicle transport. It might work out with a drill but not with a less energy intensive appliance. Life cycle thinking needs to be incorporated to business models and decisions. You also have to look at a social value part. You have to consider convenience vs inconvenience. You could consider localised drill pickup points in a grocery shop for example where you go anyway to pick up other essentials. Social value is very important because without it most schemes won’t work. Maybe you could have one drill and you pay an annual fee for handy services from a shop like a B&Q. CE is going to be very difficult.

What about CE with respect to metals?

That is easy. They are usually in bulk. Cars will have around 700kg of steel in them, about 100kg of aluminium more a bit more if the engine is cast in aluminium. Cars are straightforward and worth recycling. There exists infrastructure that supports this. Buildings are also easy. The diamond building is mostly concrete with some steel reinforcement. At the end of life it would be hard to recycle the concrete. It would probably go down a grade. If it were steel it would be remelted. **Remember the steel industry is already a form of CE**. **It could be a better CE if it reused things**. If you try to keep a material at the highest utility value at all times, and let's say for instance you have a steel beam, it holds buildings up, and you take it out of an old building into a new one that would be reuse. If you could not find anyone that wanted that beam, it would probably left in a store somewhere. It would be better to take it to a steel plant and melt it down and manufacture new sizes that people want now. That's recycling vs reuse. Reuse sounds great but the practical technical difficulties of reusing steel are quite high. How do you begin the business model? Do you begin your business model with an empty warehouse and wait for old steel to come? You might have to do some remanufacturing to bring to the required size and length. It is doable with also legal challenges and standardisation issues. Building regulations change over time. Concessions might be needed to support CE.

An example of CE is the milk man and the glass bottles. They would drop off the milk bottles and pick them up the empty bottles the next day. They would ask you to rinse the bottles slightly before they sterilise them. It is not popular now. Supermarkets sell milk cheaper now and have done away with the milk man. People tend to buy milk in plastic containers. Social economic factors have influenced the consumer to be more wasteful. Social value has also influenced decisions as glass can be seen as less safe. It is going to take a lot of thinking to understand consumer behaviour.

Looking at steel reuse, **Could you start designing steel beams that are standardised for reuse?** The next architect would have to know when designing that they reusing beams. You would have to get a technical standard. Material wise you have the problem of strength and regulatory barriers. You might collect all the stuff but it might not be strong enough or meet the standard for a particular application. How do you deregulate to allow it to happen? Would you then affect the safety of the building? If that happened then the social value would be gone. You don't need steel strength everywhere. It is done for convenience of the builder. Otherwise it becomes more complicated. Logistics comes in. Who makes money out of it? Is it the owner of the building, the demolisher or the waste contractor? Demolition contractors would be an interesting stakeholder.

How did you deal with scrap while at Tata?

It is quite common for big companies to contract out their utilities same with slags. The big Tata sites for their internal scrap arising would just put it back in the production cycle (melting pots). That maybe happening here. The small scrap dealers might be sorting it for the big companies to remelt themselves. Some slags contain metal scrap and it takes time to get it out. The scrap merchant may demetalise the slag and sell both. In the steel industry you have companies like Tarmac that deal with all the slag. They are a cement company and also own mines. At Tata there would be quite a lot of waste contractors on site taking a lot of the waste streams and people looking for new markets for the waste streams because they are trying to avoid landfill costs.

It is argued by people in the metals industry especially those in steelmaking that the definition of waste needs to be re-examined because of the steelmaking by-products are used in other processes, would you agree?

You are talking about something that has been going on for a long time. Have you heard of zero-waste? The end of waste regulation is the point at which you say it has been sufficiently treated now it is a valuable commodity. Scrap has always had value. It was initially characterised as waste. Had it retained its waste status, companies would have needed a waste management license to process scrap and many regulations to abide by. After a long battle, they won the right that scrap received by steelmaking plants is no longer considered waste. Waste definition and regulation can hinder recycling. Regulations have different angles. Every stakeholder has an agenda. When at Tata we used to send waste oil to Port Talbot where we put it in the blast furnace and combusted it creating energy and leaving no waste and little environment impact. A new regulation came out and stopped us from doing so and we had to hire a waste management company to separate the oil and the only beneficiary of the regulation was the waste company. There are lots of literature and years of arguments on such issues. CE should rationalise those in a life cycle way and offer the best solution. In japan, they seem to be able to do this. There is less flexibility in our bureaucratic process. You should look at the institute of sustainable resources at UCL headed by professor Paul Ekkins. He set up the landfill tax policies and would regard that as successful. It has driven waste management to a new level. He would say there are a lot of gangsters and criminals involved in waste management.

It appears that scrap dealers have a negatively by the public, do you agree?

Yes. There have been issues of metal theft. The BMRA would try and uphold regulations. EMR are the biggest in the UK. CE to them might be more scrap but if you maintain scrap at highest level of utility, you might end up with less scrap. They could argue that they would have **more rigorous scrap sorting because if you don't mix the scrap it could lead to higher utility.**

What is the missing incentive for CE?

I think **its supply chain collaboration**. And **how to create trust across the supply chain** and how to make sure there is good value in it for people. It is hard to do. EMF might have examples where it has worked. There is a need for more research than narrative. We are working with BSI on a document is attempting to do that. It is however a lengthy document. How will people start to use the document? People suggested a guidance document. It should be intrinsically there in the document. The template could be easier. How does our business work? What do we produce? How do we produce it? What waste comes out of our processes? What happens to our products? What waste are as a result of our products and why? Which is the most important the process or products? **You might consider only solid waste** but if you include energy and C02 in a life cycle context, it becomes more complicated. In CE the aim is no waste. In a CE the idea is you need to minimise inputs as well as minimising outputs. You need to list the inputs and outputs. If you go for a very basic definition e.g. solid waste you could in theory burn everything but you would be left with tonnes of c02, but you are avoiding energy consumption. Would you be decoupling then? Tim Jackson's "Prosperity without growth" questions why is growth measured in economic growth? He proposed alternative KPIs to GDP such as wellbeing and happiness. GDP is pounds per head. You could argue literacy, healthcare. The politicians did not like that. Another thing to look at is the Stern Report.

Secondly, you have also to look at the consumer. We have to look at behaviour. Some consumers throw everything in the black bin. Looking at steel, **it doesn't matter if it goes in the black bin**, the magnets will be able to sort, separate it and remove it before it goes into incineration at Bernard road. Unfortunately copper, lead will not. The incinerator provides steam direct to district heating. How could they afford to it? The district heating pipework were already there since after the war. The turbines produce electricity and steam. It is not bad. It is pretty circular. It is avoiding the fuels. The steam goes to the hospital. From an LCA perspective, I think it would be good. Apart from the visual and social impact, it is fairly central so pollution could have an effect but the height of stack may negate that. It is not dirty and very well managed site. I think the negative points are not as strong as they used to be. They are well regulated and comply. The site has to be there to take advantage of the existing district heating pipework. You would not necessarily build a new district heating system just for the incinerator.

What policy and practice would you recommend to promote CE?

- You should consider externality costing. Integrated profit and loss accounting.
- Life Cycle Thinking, Whole Life Costing, Life Cycle Costing LCC.
- Data sharing and big data; tagging and monitoring and tracking material to know the exact components.
- Exemptions for circular businesses to incentivise in addition to taxation.

Top-down or bottom-up approaches to promote CE?

It is a tough question. I think it might require both private and public drive.

Is there anything you would like to add?

There is the issue of accidental circularity or unintentional circularity such as Apple and ITunes, Uber, Netflix, Spotify, Amazon prime. You can rent and stream music and videos. Suddenly you don't need to buy CDs and DVDs anymore. **They have eliminated material use termed "Accidental dematerialisation".** You pay for the service and also own digitally. Uber could promote the sharing economy. It is not like these companies set out to be circular. Inevitably Scrap has an exergy value (embodied energy) and is worth something and it is easy to exploit it by melting it. It is much lower energy than primary steel production. It is not the intention of being circular but the economics were clearly definitely there. The economics were not evidently there for these new services but the social value is so high. I was home listening to songs and exploring. I was only using the battery of my phone and internet connection. They add social value. **The social value factor is so important**. It improves people's lives better. Uber is cheaper. **Maybe CE should be about empowerment of people and focus on social value.** Why should I bother recycling this cup? There might be some incentive to do it. Someone needs to check it works. These guys have dematerialised by accident. I am sure the LCA would be good. Apple products may need more recyclability. It might actually even help sales of dvds and blu-ray discs for the collectors.

TRANSCRIPT OF INTERVIEW WITH N-B

(Former National Leader of a political Party in the UK and Candidate for MP seat)

Policy makers as stakeholders in the metals waste reuse and recycling supply chain in the transition to a closed-loop/circular economy. (PM)

INTRODUCTION

Key: Q: Question NB: R: Response

NB: What course and how long have you been doing it, where are you from?

R: Research area; sustainable supply chain and focus on recycling and reuse of raw materials

We have looked at the justification of metals reuse and recycling from an economic and environmental point of view. Despite clear benefits, there is a lot of room for improvement. We therefore decided to investigate further and explore possible drivers, barriers and policy implications from a multi-stakeholder view. Through the use of a stakeholder model, we mapped various stakeholders in the metal waste supply chain. One of the stakeholders identified were Policy makers.

Q:

NB: I not an expert in the area but I have some general philosophical views that might be useful. I do have a science background. My university degree was in agriculture science. If you are talking about waste, I am more likely going to be talking about food waste because it ties in with that area, but a lot of the general principles will cut right across the board

R: food waste is an important topic that receives a lot of attention. Even though metals offer an easier and shorter route to recycling and CE. It is argued that the metals have equal importance especially given their wide range of applications

NB: coincidently, I took an old microwave to a recycling site (Glead) over the weekend and sat in a queue for 20 mins to get one microwave. Something not quite right. We need **much better systems.** It is not surprising much of that still ends up in waste streams or indeed dumped (landfill)

R; Not many people even go to the Recycling centres

NB: And here I am complaining about the process.

R: hence the need to look at the situation from a qualitative angle both in short and long term.

NB: this may apply as metal recycling, I am about to buy a new mattress, last time I bought a mattress, trying to find someone that would recycle the old one was a really struggle. Now all the main suppliers seem to offer that. You have to pay for it but at least it's easy. **It's some**

small progress but I have a feeling that in somewhere like Germany, it would be easier and probably free.

R: yes, they may have more directives and initiatives. As I have been studying CE, especially within Europe, Germany is ahead of its counterparts. They have had directives of their own, way before EU directives, promoting circularity

NB: my understanding is they also have rules for standard components, usually labelled so you don't have to recycle it, you can simply reuse it which of course is much better.

Q: How do you define circular economy? (In an ideal world, what would the economy and society look like if it was based on a circular economy?)

NB: I haven't seen a UN agreed definition. The CE is a **necessary but not sufficient** condition for us to get to the stage where we have one planet living, where the human race is collectively living within the resources of this one fragile planet while ensuring everybody has access to a decent quality of life. CE is part of that but it is not enough on its own. I think it's important to say that because sometimes people think oh we've done the CE and that's solved all their problems and that's clearly not the case. We also have to look at the consumption levels. But within that I think is obviously important. Its means zero to landfill, **zero waste or very nearly zero waste**, where by any resources that have gone into manufacturing, that have gone into food production, that have gone into things we rely on, physical objects around us, doesn't go out the other end and simply goes going round and round. The ideal situation would be **if things lasted a long while**. An important part of the CE is an **end to planned obsolescence**. When I was a child, I remember people had fridges that had lasted 40-50 years. I recently had a fridge that died after 7 years, I was complaining and people said it was the average and that I had done quite well which just horrified me. We obviously can make fridges that last years. Why aren't we? That's the problem of planned obsolescence. We also need to make sure for example sticking with fridges that as many components as possible are reused without having to go through any recycling process that invariably requires additional energy. So part of an CE should be **standardised parts**. That you can simply reuse rather than reprocess. I am not a technical expert but there should be some parts (volts, bolts, part of the compressor, sheets of metal without re-melting them) that can simply be reused without recycling in an ideal world. Final step would be recycling everything that is not suitable for reuse and putting it back into the system to produce new products.

Q: would that not cause an economic problem if most companies aim to maximise profit? Is there a need for new or different business models?

NB: there are two things that I think are key to this. Let us take planned obsolescence for instance. there are a lot of externalised costs that the manufacturer does not bear. But we all collectively bear. That's the use, all so often ending up in the landfill, of a value scarce resource, that's a cost to all of us, energy cost, these days most of the carbon emissions associated with the energy costs there, now all of us bear the cost of that, but it's not on the manufacturers bottom line, so I am in favour of green party policy to **replace VAT** with what I call **damage taxes**, so that will be the idea that you would actually measure the actual impact of a product and I will take an example of a t-shirt. A t-shirt now, you might buy it of for £5 down I Primark but the externalised cost of that might be anything from a child forced out of school in Azerbaijan to pick the cotton, whose not going to get the education they need, thru from the carbon emissions to transport the cotton to China where its spun into cloth, in a river filled with dye into a river that killing the river and damaging the health of the people that live downstream, fossil fuel emissions of Bangladesh where it is sown in a garment factory (we all know about Rana Plaza), fossil fuels coming over to Britain, sold on the high street, by someone on a zero-hours contract, minimum wage insecure job. That t-shirt costs vastly more than £5 but that's all that's on the price tag. If we were to for example, have growing hemp in Britain, in a lovely ecological organic field, spun down in a factory nearby, with really good working conditions and environmental standards, sold thru a fair trade shop, where everyone is paid decently, its cooperative. At the moment, it's pretty much impossible for that t-shirt to compete with £5 Primark one. But if you put all those externalised costs onto the Primark price tag, quite possibly it could. So one of the changes we need is to ensure those externalised costs are actually on the price tag of manufacturers/makers bottom line.

Q: how realistic do you think that is?

NB: there is an organisation known as the Carbon Trust, they have a carbon footprint, I think they also have a water-footprint and waste-footprint. Now if they were able to develop a social-footprint, which would take in children forced out school, garment factory conditions, fair wages, etc. if you put those four things together, they would be, a lot of factories are already producing the figures, they would give you what you needed to know to levy that appropriate way. So it's possible to do it. Most of it is already being done.

Is it politically possible?

That gets into a whole broad field. We have had 35-40 years of neo-liberal politics that said greed is good and inequality doesn't matter, we can keep trashing the planet. I believe, I would that politics is coming to an end because it has failed even in its own terms. So it's time to replace it with something new. A struggle for a CE, one that acknowledges damage created by products is part of that political change. We need to go in the right direction, not the wrong direction.

Q: in this proposed move to CE, what do you see as the role of policy makers? How can they make a difference?

NB: before we go into policy, starting on politics, we need to point; we were mentioning earlier about Germany and how much better it is at these things than the UK, we need to point at places where some of these things are already being achieved and say this is perfectly possible, there is nothing extra-ordinary or radical about this. There are parts of the world that are already doing this. So do the politics, we have to point to that. We have to point to the fact we cannot continue the way we are doing now. We are trashing the planet. We are hitting right up against the planetary boundaries. We can all have a decent standard of life but we can only do that in a circular economy world. Then you create the rules. I think getting externalised costs metered and accounted for is absolutely key. But also policy makers can set minimum standards. Some of those externalised costs, insecure jobs, low wages, poor working conditions, it is up to policy makers to set standards for that. One of my pet examples, although it is getting better, every phone used to have a different charger, we all accumulate in that bottom drawer somewhere a whole collection of old phone chargers. We only need one standard charger. Once you have one, you'll only need to replace it when it dies. You don't when you get a new phone, get a phone charger. There are improvements. Apple ltd is failing to cooperate, as with many things is a serious offender. The responsibility has to lie with the regulators to stop a company although of course other people are producing phones in very different ways such as fairphone and are doing ok. Apple could choose to prioritise and it would be right in line with their brand.

Q: when it comes to pointing the finger at places where CE is a success, China is at the forefront. However china is a planned control economy. Do you think CE might be better suited under such an economic system?

NB: I think Germany and the Scandinavian countries, although in this area I know less about it, they demonstrate it's perfectly possible in a western democracy. One of the things I'd say is, I did a debate recently at a university, and the title of the book was "against democracy". The author was using the examples of the US and UK, basically saying that all democracies failed. My response to that is let's try democracy first and whether you take on CE or take it on social measures like low wages, it is actually the most democratic countries, ones with the fair proportional voting system that score best/highest on any measure you think of. So I don't think autocracy is the answer. It is certainly true that in an autocracy, you can do certain things. One of the long-term problems is that if something is imposed, how organically does that become part of society in the way it operates? If something is just imposed from top-down, at some point history tells us top-down authority like that will eventually disappear, if you haven't organically created a situation where that becomes the norm and the social practice, then may be that's a less sustainable political model of creating policy.

Q: so you do believe it can be done here, given the current political system?

NB: yes. I'll be optimistic. We currently have a government that has the support of 24% of eligible voters, that's how people voted tory in 2015. We have an elected house of lords, we really don't have democracy. Even in this system, I still reckon it is achievable. I think it would be easier in a proper democracy.

Q: How can policies be translated into actually practice?

NB: we need to make policy sensibly for the long term. I think that's one of the key problems with Britain's current system. It's partly as a result of "First past the post" where you traditionally Seesaw between one side and another and the traditional thing that happens when one side comes in, it undoes as many as possible the things done the opponents have just done and so you have this seesaw effect in policy. What we are talking about are policies that need to be planned for 20-40yrs time. We therefore need to change the policy making process. So that you, I draw from my example of this Norway's pension policy, just as an example of how to make policy and this comes from a book by a guy called Stein Reingen titled "Nation Of Devils" and he talks about how Norway made a new pension policy. It basically over 10 years through 3 different governments, they had white papers, green, blue etc., they consulted workers, employers, consulted everybody over a 10 year period, they got to an agreement. Everyone agreed this is the new pension policy. Every political party was signed up to it, the employers were pretty well, the unions were, and they implemented it. Everyone knows it's going to be stable policy for the next 20-30 years at least.

They have a proportionate representation political system. Everyone kinds of expects they have to work together because that's the kind of governments that you get. And there is a sense that some things are not part of the political points scoring. And if you try to point score from them, you would be the one who suffers. This is a really important thing that affects everyone's future. Pensions are everyone's business to some degree. They have policy areas where there is a general sense of "we have to get this right "and we are all going to work to get this right.

I would say that circular economy and things like that are similarly important to our long term future, so we need to, I am talking about the whole **transformation of the entire political system** but nonetheless we need to try and move in that direction, where policy is made **after seriously consulting all the stakeholders**. I do have an example where this actually works. I was told about how we created the standards for home energy efficiency, the standards that the Tories in 20106 entirely demolished. What happened was the minister put groups such as help the aged, charities, NGOs that work for vulnerable people in the room with the building industry and said I want all of you by the end of the day to have agreed on standards, what you think is achievable, can you get to energy efficiency levels C in 95% of rented homes in 2020?. The minister said if you two sides come out and agree, I will implement it, and that's what happened. The minister said if you don't, I will just make up whatever I like myself. It concentrated minds wonderfully. It doesn't have to take 10 years. It is a matter of getting the various stakeholders and interest groups together, saying you all have to be sensible, tell me you're the experts, tell me as a politician what the right technical answer is. I'm giving political direction that says we want more affordable comfortable to hear homes, you tell me how to do it, I'll go away and do it.

Q: is there a need for both short and long term policy?

NB: How you get there will depend upon where there is? But certainly if you want to get to a circular economy, say in metals, maybe you start with 50% and say next year we want to get to 55% and the year after you go for 65% or whatever. But basically it's the experts that tell the politicians how to deliver the policy goal and some degree what a realistic goal is. There is no point in saying we are going to have a CE tomorrow, that would be nonsense. What failed in Britain was the Tories were not signed up to it and threw everything out. What you need is all the politicians in the room together, at least all the significant ones, and knock some heads together until they all agree to sign up, to saying this all important and we are going to sign up.

Q: stakeholder engagement is vital then?

NB: very much so. All the stakeholders need to be in the room. It's the policy maker who is saying you all have different interests and need to find a sensible way we can get to and work together. The politician provides some guidance but the stakeholders all have input into how you get there. What kind of rules do you need, and you are always going to have worry about the rogue and the pirate who are dodging the rules and how to stop people going rogue. It's going to be the stakeholders who have the best ideas to handle that.

Q: as a candidate running for MP Sheffield Central, what are your key campaign targets and promises?

NB: I am afraid CE won't be on the campaign leaflet, but it will be underneath and behind the election leaflet, in terms of what we want is **warm comfortable affordable to heat homes** for everybody, something that appeals to people on a personal level. Taking that an example, obviously there are things we need to do, in an effective environmental friendly way, landlords chuck in cheap double glazing that only lasts a couple of years, pvc etc. what happens to that at the end of its 10-20yr lifespan? Look at what kind of regulation you can create to ensure that you put in windows that last a life time. It is difficult. There is a political mismatch between the political cycle of say 5 years or less election, in which if you do something it wouldn't payback until 20 years, certainly in the current political system, you don't get any real political credit for it. We may need a change in the system. Any new houses should be built to near passive house standards, so you basically won't have to heat it. That would mean solar panels and real good insulation.

We are also campaigning on the issue of air pollution. Like most parties we are talking about getting low and zero emissions at point of use i.e. taxis, buses, hybrids, hydrogen, fuelled electric vehicles etc. we are probably the only party talking about reducing traffic, congestion and private vehicles on the roads and replacing them with more public transport and the encouragement of walking and cycling. From the CE point of view, that would mean creating vehicles that would last a number of decades i.e. trams, buses etc. that would be used by a lot of people relative to the material costs of manufacturing them (what you put into them), fewer private cars, car clubs for access when you need it, so instead of having 10 households with 15 cars, maybe you have 10 households using 5 different car club cars.

Q: would this entail a move to a more shared economy?

NB: yes, Very much so. I was this morning at a protest, arguing for free train travel for the elderly within Yorkshire. If you make travel free, people can be less lonely, meet friends/relatives, and go to clubs more easily etc. providing people with more accessible public transport affordable or free for the elderly is a great thing to have. They are human wellbeing health policies as well as environmental policies. I think we are starting to get some cut-through on, is the understanding that it used to be thought that that green stuff/ environmental stuff, you had to give up things, and it makes our lives worse. We have been trashing the planet and making life miserable, what we can do is we can stop trashing the planet and create a better society and getting that idea across for me is the greatest political challenge.

Q: so you are looking for policies that have a socio-economic impact as well as an environmental one?

NB: Yes, a third policy and a very important one is education. I have talking a lot about how our educational system prepares pupils for exams, not preparing them for life. And this comes into a broader understanding of the physical world and one of the things that British education has entirely got away from is contact with real physical things. Anyone who is considered good at school won't be doing wood work, metal work, arts, cookery etc. they are the subjects for the other students but everyone needs to be able to interrelate to the physical world, to have a kind of basic understanding of the physical world. I think a genuinely holistic education that takes in that and contact with nature would also then prepare and produce citizens that can better understand the arguments around CE.

Q: One of the barriers to CE, waste management and recycling and reuse identified in literature is lack of knowledge, what is your take on this?

NB: Yes, this is going back a few years but I was in Camden, going about with a green rosette on, canvassing for the elections, you would not uncommonly get someone who had seen the rosette come up to you and say hang on, for example a woman came out with a huge armful of bottles and asked which ones of these should I recycle? I wanted to talk about the election actually, she was really trying to do the right thing but didn't know where to find the information. She was an educated middle class woman.

Q: while speaking to other stakeholders, a common problem identified was a lack of collaboration between them, what is your experience on the issue of collaboration and coordination?

NB: This is true. There is also no coordination between local councils. Particularly in London, if you move between boroughs, which lots of people do very often because of the nature of the housing system, every borough has different rules for recycling, so people have to try and figure out what this boroughs rules are compare to the other borough that might be just two streets away that they lived In previously which is crazy. There should be **country-wide standardised systems** and one of the things that means is that we have to get away from the **energy from waste systems** in the form of incinerators. We have a prominent one here in Sheffield and it is the reason why Sheffield is at the bottom of the league of recycling in the country. Once you create a beast a monster like that, you have to feed it. It discourages you from reducing your waste stream which is an incredibly counter-productive thing to do.

Q: operators of incinerators argue that they not only provide waste management solutions but also electricity and much needed heating, how do you respond?

NB: This is true, but I would argue that if you took the products from the incinerator and **reused and recycled** them, you would create vastly more jobs, more income, more public benefits from recycling those and there are also concerns about health impacts of incineration. One of the things that is going to be become an increasing issue is that at the moment incinerator operators get away with saying "there's a lot of pollution out there and ours is only a tiny extra percentage". When we finally reduce air pollution from other sources, particularly motor vehicles, their emissions are going to be a much higher percentage which is going to make them much more problematic. I've spoken a lot of incinerators nationally all around the country. A success story was in Norwich where the greens campaigned against an incinerator that had already began construction and the contract was actually pulled costing around 10 million GBP. Another example is in Cornwall where locals put up a strong fight but sadly lost, you win some, you lose some.

Q: what do you think will be the role of policy post Brexit? So many policies are EU Policies

NB: The worst case scenario is that UK becomes what it used be known as the dirty man of Europe, and that is referring specifically to the fact that it was the EU that really forced the

UK to clean up its beaches but we can extend that to things like getting rid of waste targets, getting rid of anti-pollution targets etc. the positive side is that there is going to be a huge pressure, both public, political and global pressure not to do that. I was in Marrakech for the climate talks, it was the second day Trump got elected and understandably there was huge sense of shock and I got there a couple days after that and by that stage, people had already gotten over it. People were saying that if Trump abolishes all these environmental laws in America, countries like China would end up putting tariffs because these are dirty products. Tariffs would make importing American products more difficult. If the UK wants to continue to do business with other countries especially within the EU, we are going to have to stick to EU standards. Lots of the rest of the world is going to demand similar standards. If the UK is to be an export economy, there will be lots of pressures and forces that are going to try and keep at least the standards we've got now. There is going to be balance. No perfect answer at the moment. Lots of the better producer would want to keep our standards, while the low cost producer might not, seeking to increase output and profit, the influence of the two differing sides will vary from industry to industry, place to place.

Q: what do you think will be the leadership role from stakeholders in the move to CE?

NB: I think it's harder, it depends if they group together**, perhaps the biggest company leading,** saying we want this, and saying to the government we want good standards, even great standards, that's obviously going to have a positive impact, the problem is going to be if they just implement those standards without regulation, they can be undercut by dirty/wasteful producers, so there is a tension there obviously between doing things right and doing things as cheaply as possible.

Q: is it therefore the role of government or the private sector or both to take the leadership role among the stakeholders in the move to CE?

NB: I think it's the **policy makers** that have to be the leaders, partly because industry even the best ones should be pushed to do better, so if you get producer A who means well, obviously the policymaker can look towards that producer to see what is possible because they are already doing it, in any situation you should be able to say how can you do that a bit better. You don't have to make such rules from day one but how can you set a pathway to get there or that far. Ultimately the leadership has to come from the policy maker and leadership has to then ultimately come from politics**. There has to be political leadership**, setting a challenge. If you look at air pollution in Sheffield, 500 premature deaths a year, we have to be able to do better than that, ideally get that figure down to zero or as close to zero as we possibly can. An example is a campaign aiming for zero road deaths that is supported by the Green party. Politicians often say UK road death toll is not bad say compared to France's, that's not nearly good enough. We should be saying we are going to aim for zero. I doubt you can achieve a 100% zero but if you set it as an aim, you are going to get it as low as possible and that's the sort of thing you need a political leader for, to say even if we get to say 200 deaths on British roads last year to still say it's not acceptable, we still need to get it down to say 20 and after you reach 20, you target an even lower number.

Q: you've talked a lot of job creation and wages while campaigning, don't you think the metals sector should be given a lot more attention especially given the number of jobs created in the sector from producers to scrap dealers etc. ?

NB: It's an underrated area and it's an area that I will stress I am not an expert in but some of the things I have encountered over in Shropshire, a wildlife trust after a huge struggle there managed to get a metal dealer shut down known for running around, dodging the rules, left a site in a hell of a state right beside a site of special scientific interest. So there are still some cowboys out there. Another horrific example is down in Birmingham where a wall collapsed and 5 Gambian workers were killed in a scrap yard. It is an area that is **traditionally not well regarded and respected**. But it is enormously important and is potentially creating really good jobs. The idea that someone sorts out waste is traditionally regarded as a low status job, but actually it's a really important job and there is no reason why it can't be done in perfectly reasonable and safe working conditions with appropriate safety gear and whatever else you need. The person that is bolt by bolt dismantling a used car and ensuring that every part gets reused is doing a **hugely social service** and that isn't **recognised** and it **doesn't get paid** for properly and **that needs to change**.

Q: to add to your comments above, speaking to residents we found that there is a negative perception about scrap dealers; do you have anything to add?

NB: my understanding is that you cannot now buy metal for cash, it has to be documented with a paper trail, and the regulation should be squeezing the real cowboys out of the business and allowing the better operators to flourish.

Cutting metal miles instead of food miles

Thank you so much.

TRANSCRIPT OF INTERVIEW WITH N-C

(company y, Group Health Safety and Environment)

Primary producers of metals as stakeholders in the metals waste reuse and recycling supply chain in the transition to a closed-loop/circular economy.

Thursday 25/05/17 3:30pm, Hadfield building university of Sheffield

INTRODUCTION

Key: Q: Question NC: R: Response CE: circular economy

Introduction

Name? NC Years of experience? 14 years

Q: What is your role within the organization you are working for?

NC: I work within the Environment division, looking after all company y environmental issues to do with European operations, mostly UK and the Netherlands and Europe. Work a little bit with India but they have their own team there. I am involved in policy development, environmental policy, part of the EUROFER, the European Steel Association, I also carry LCA studies for our products, produce EPDs, studies to show benefits of our new products vs old products or products of our competitors. We work in construction, automotive, packaging and energy. I was also a work package leader in a European study called STYLE which has just finished.

Q: How do you define circular economy with respect to the metals industry?

NC: Particularly in the steel industry, it is about taking the materials we have and either reducing the amount of material we use or it could be about reusing remanufactured or recycled materials. It is kind of a waste hierarchy we start off at reduce, recycle, remanufacture and reuse. CE is about designing products that basically close the loop on material recycling or designing things that reduce the amount of materials needed or extending the life of a product. Fundamentally for me, it is about reducing the environmental footprint of a product by using those approaches. It is quite possible to I think a bad way of thinking of CE is to just say we use more recycled materials in our products because from an environmental perspective there might be a lot of processing that is required to convert that material into something that is something that is useable. It should always come back to what is recycling worth? Is it worth recycling? Rather than saying recycling is good in all instances or reuse is good in all instances. I think that's why life comes into it a little bit. You could have a product with a very short life but you reuse it a lot and somehow that seems better than a product that lasts longer in the first place. I think that's why there is a slight difference between, its importance to bring in the "life thing" because we could design a lot of products that are energy intensive to recycle and reuse or might be very lightweight but not necessarily have the same durability. There is a lot of focus within CE on reducing recycling and reuse, I think it is important to consider what the **environmental impact** of that would be.

Q: From the definitions there seems to be an emphasis on regeneration and restoration, what is your view?

NC: I think sometimes it's done for simplification, trying to make it something simple for people. I think you have to do some background work to show at least from a life cycle POV these lead to environmental benefits

Q: Do you think the concept is not fully understood and hence the attempt to simplify it?

NC: I people are always looking for ways to simplify an environmental topic into something that is a bit more catchy, grabs people's attention and then perhaps you move make progress in a certain area.

I think the concept of circular economy is in a sense good, helping to highlight some of the benefits by bringing the economy into it, businesses are always interested in economics, economic benefits, not necessarily much immediate environmental benefits, so quantifying it in terms of financial ways or bringing this idea that you can boost your business revenues, that's quite a good way of presenting it. There is definite value in rebranding things in certain ways just to catch people's attention.

Q: it is argued that CE is a rather ambitious paradigm, what do you think?

NC: we have concepts like zero-waste, fully circular products are kind of aspirational rather than necessarily in practice what would happen**. I agree**. In steel there are examples where it gets material management 95% where 95% of materials are recovered and recycled through the life cycle of a product e.g. steel in vehicle cars, a lot of that material is recovered, reflected in its economic value as scrap. **For metals the CE aspect of recycling has always been there for a long time, perhaps not so much in terms of reuse though and remanufacture,** whereas if you look at plastics, it tends to be less so, so the emphasis for them maybe would be recycling after-use. For us in terms of new concepts and development, it is not so much about recycling because that is well established field, that market already exists, its more about exploring opportunities for reuse and remanufacturing. Having said that there are opportunities to think about and revisit whether recycling using recycled material is an opportunity for the UK? We export a lot of scrap, should we perhaps use more scrap in the UK? Rather than exporting it, is there an economic case for doing that?

Q: how much of your operations are based on secondary steel production from scrap?

NC: We used to have an arc-furnace in Rotherham which we sold to liberty steel, British steel uses a blast furnace that uses about 20-30% scrap, Tata steel only has one main operating site in the UK and that is Port Talbot in south wales, 6 million tonnes of steel through a blast furnace.

Q: is there a reason why the blast furnace route is used more in the UK? Does it offer an advantage?

NC: It's a number of factors, its economics, it may also be due a product mix; certain products lend themselves to being manufactured by BF Route rather than an EAF route, it is also worth noting that the EAF use other materials other than scrap, some EAF can run on primary material as well, it doesn't mean it is always scrap. An EAF uses a batch process, while a BF is a continuous process and there are much more economic investments in a BF and you run it for a longer period and as such you are committed for a certain number of years (e.g. 10-15 years). The EAF is shorter term. So once you make that initial investment, you are left with what you have, locked in. operating costs and electricity prices are quite high in the UK compared to other regions. If the price of scrap is high and the electricity price is high, it is not really economic compared to the primary route. As a result you see a lot of material being exported, if the price of electricity was to come down, maybe companies will be willing to pay more for scrap.

Q: is there a reason why the blast furnace route is used more in the UK? Does it offer an advantage?

NC:, absolutely, When we think of LCA, we look at the whole life cycle, if you think about the environmental impact of making the steel, that is cradle to gate, there are differences between a BF AND EAF, from a whole life cycle perspective, it can be a lot more complicated because what is commonly done in a full life cycle study is to evaluate impacts of the scrap and so just as you are buying electricity, you say this is a valuable raw material, and it has upstream environmental impacts and if you are buying scrap, you assign some CO2 to the scrap but on the output side, when the product comes to its end of life that product becomes available and that is a product out, you get a credit for that, so your inputs and outputs of scrap are debits and credits and this kind of normalises the two technologies, they start at odds but kind of even out at the end. If you look at EPDs, this is kind of captured in the module D.

Q: In your opinion is there any benefit of EAF (circular) production?

NC: the main advantage is not so much in the life cycle sense; it is more about reducing your environmental impacts and your liability locally. For our production sites in the UK, it means we reduce our overall emissions from the UK; it may not change anything on a global sense. If we use more scrap here, that means there is less scrap for export and somebody else has to make more primary steel. It is a balancing act. Using more scrap does not necessarily make more scrap available, there is a limited amount there, it is just about who uses it so to speak. The only way to make more scrap available is to design our products so they can be recycled and reused. If a product at the end of its life is not economic to pull apart and disassemble, that's when the problem arises because that product is then not economic to use in an EAF process. You should design for rather than using recycled content necessarily because that won't change the steel market so much, it is about designing products that can be recycled or reused at end of life. You should think about how you disassemble products.

Q: does the long life of steel products especially in construction affect the volume of scrap its available?

NC: yes. Is that a good thing or a bad thing? I think it is better to design things to last longer instead of recycling them every few years, adding to the overall emissions. When they do reach their end of life, they should be designed so that they can be reused and recycled. It is different for different materials. For plastics, there is not a market for recycling is not well established as in the case of metals but I think it is growing. There is a case for saying we should more recycled content to help drive the market for plastics.

Q: do you think the concept of CE should be further promoted in the metals industry or enough being done already?

NC: it is a good story for metals because metals have been part of the CE for a long time, so getting metals recognised as circular materials is important for us as compare to competing materials, so that's why we like to talk about CE, because we think we have a good story already. In terms of what we can do more of, there are some opportunities to explore in terms of reuse. I think this is where the challenge is. How do we capture more value from reuse? How is the business model for reuse? There are positives as well as challenges.

Q: in your supply chain dealings, do you deal and interact with local companies or is it more international?

NC: because we are a big exporter, we are fairly local; we don't have much experience of trading scrap overseas. We have relationships with ERM and those kinds of organisations within the UK. We also some have these relationships with some of our customers. In our scrap yard, we have materials coming back from our automotive producers. With packaging steel, there is what you call a packaging return note system, it is like a credit note system that goes around with the material, we get if you are a recycler you get paid money so we take packaging scrap back and we get some revenue from that as part of this PRN, the producer is obligated to pay if you produce packaging you have to pay for it and that material goes to the end, the person who does the recycling and is passed down the supply chain. That is kind of a more local thing as well.

Q: there are quite a number of small companies in the metals supply chain operating within the Sheffield region, do have dealings with them? Or are put off by the negative perception?

NC: I don't think we buy from such small players, we deal with big scrap dealers like ERM, Maybe the big dealers interact with the smaller dealers, I really don't know. Maybe there are some middlemen and brokers. I don't think they are selling to an end-user but maybe to another scrap dealer. There is probably a hierarchy.

Q: do you dispose of some of your waste scrap to the small companies in the metals supply chain operating within the Sheffield region?

NC: most scrap is recovered for recycling within the plant unless it's a different metal or something. For example, maybe there is some aluminium mixed in the steel scrap, we separate it out and sell the aluminium because we do not need it. So if we receive material that is mixed, we do some separation and some of that might get sold. If we have an excess of scrap we sell it.

Q: literature on CE suggests that China has been most successful in the implementation of CE, with eco-parks and cities and top-down approaches and it is argued this is due to the centrally planned nature of the economy and that it may not be so easy in a neo-liberal economy, what do you think?

NC: an integrated steel works in the UK would have a cement plant on it; it would also have a power plant to take the process gas and turn it into electricity, in that sense those activities would be the same. It may take longer in Europe to get it set up. Steep production is already pretty circular. It all comes down to economics. If it is economic to do so, people would do it. If we have waste that we can make money from selling, we will. I think it gets more complicated when you look at things like waste heat. Maybe there is a need for some incentive to recover waste heat to use it for district heat. We don't do waste heat due to economics.

Q: if we are to move to a more CE, Who leads the way?

NC: I think it is a case of business has to adopt it, has to be led by business but in order for that to happen, it has to be facilitated by government either through research, like this one to get to the bottom of the barriers, some real demonstration of how these things might work in **practice.**

Q: I'm sure you have seen the EU CE Package, has it taken a reductionist view with a focus on waste?

NC: It does cover end of life vehicle directives and things like that, that's about designing things for recycling, there should be incentive to design for reuse and recovery of materials, one of the key factors is defining what we mean by recycling, if a material is, we need to be clear of the point of measurement, sometimes regulation can lead to some unintended consequences, we In EU define the recycler as the person as the person who recovers the waste, so we say its recycled but the material is just being recovered not necessarily recycled and sometimes it is exported abroad, we are not necessarily measuring recycling as such but recovery, we are measuring a point of collection. Sometimes that means the properties of the scrap are not so good, if you define it at a point where it is still pretty mixed up, then no one cares because you have dealt with it then, it is someone else's problem, whereas if you said ok, the point at which it is recycled is the point at which it enters the steel plant, then there is more incentive to make sure that it is high quality scrap instead of it being exported as low quality scrap. We need to upgrade the quality of the scrap at end of life so we can recycle more instead of exporting outside of Europe.

Q: which primary and secondary steel benefits more from CE?

NC: You could say is you have EAF that is more beneficial because they do more recycling but if you define CE based on what I was talking about, about designing for reuse then both routes would benefit from it.

Q: how do you interact with other stakeholders?

NC: I don't deal with them in the UK, but we have some involvement in Europe, most of the regulation comes out of Europe, not much in the UK, these things are discussed at a European level rather than a local level. I am not an environment manager on a plant, I don't come into to contact with the local environment agency, I am more in strategy. In wales there is more regional involvement, devolved regions. Steel is a global business. We cannot solve all the problems. We cannot draw a box around south Yorkshire or Europe and say we are going to SY a circular economy because we can't make all the products, it's a utopian things, most UK steel demand are imported, we can't suddenly change to making all those kinds of steel in the UK, We are making millions of tonnes of a product we are selling all around the world. We also cannot take that material at its end of life back to Sheffield for recycling, because the logistics and economics of that would not stack up.

The best we can do is look at our activities and try and look at a global view and in the context of the UK how we can secure a good scrap supply chain probably through collaboration with other stakeholders especially around reuse. There are local business models around reuse that might be more interesting.

Interview with R- Manager- Metal Scrap Dealer-W-H Waste Management Company, Sheffield. Dr. Andrea and Faisal. 9am 23/11/2016

2 hours

Introduction

We are looking at how European countries could adopt policies that favour the transition to CE, alternative economic paradigm. In practice there are some hurdles. Specifically looking at the metals, while we have been able to establish from an environmental point of view why through LCA you can prevent 90% of emissions, save materials from going to landfill. Still we have realised that there are a lot of materials that go into landfill, that are not recycled, that manage to escape the close-loop. What are the barriers at the moment that are not helping this model being propagated? As the main operators working in the collection of these materials, and in the reprocessing and selling to customers like steel producers, what are the barriers you are experiencing and what are the policy loop holes preventing you from playing an even bigger role in the economy because what we understand is that your role is really crucial but we see a lot of fragmentation e.g. between the public and private sector that doesn't allow obtaining best results.

R: companies like our own are members of the BMRA, equivalent of the European association and there is a worldwide one. If I could summarise metals, first of all in the UK metals are classed as waste and it is different country by country. If you take a typical engineering country anywhere in this area, they buy prime steel (virgin steel), they do something with it, hammer, machine it, shape it and producing something. Then they have a waste. That waste in the UK is classed as waste. Really it is still a commodity. Because it is prime material for the next industry which is metal recycling. If you go to other countries they have a different approach. They take metals out of it. The UK has decided to do it differently. That creates a certain amount of issues for the administration side of business. Every company that produces waste has to register, justify where there waste streams go to. We can understand this with oils, hazardous waste material, asbestos, clinical waste. It is a huge burden on companies because they have to allocate/employ someone in their business to purely look after all the waste.

Interviewer: I was reading somewhere that there is a view that the main obstacle to circular supply chains on a wider scale is bureaucracy and this is a fantastic example.

R: We all work with European waste codes set up by Brussels and it is up to statisticians to calculate percentages, successes and failure, impose fines on companies and countries not doing what they are charted to do.

Let us go back to the very early days. In the Stone Age, as soon as metal became a desired material, it has always been recycled. There is always been an element of throwaway at end of use or life but majority of people in engineering want to see a recovery for their waste materials. You do not get a recovery for plastics, wood, cardboard unless you into big volumes, many thousands of tonnes a year. A plastic manufacturer would be able to recycle a general warehouse that has pallets and cardboard boxes and things that are delivered, they are all waste streams they have to identify, quantify and justify to the environment agency authorities. In the UK, we have various compliance schemes for waste. If you have, I used to relate it to the Easter egg, you buy an Easter egg and in the middle there is a lump of chocolate and inside that you might have further chocolate inside. While the chocolate is eaten, the wrapping is waste in the form of foil as well as the cardboard packaging for one egg. You might have a distribution pipe which might be 12 easter eggs in one carton with a label and polypropylene strap. All these things have to be identified, quantified and statistically recovered. Metal has always been a commodity of a waste stream. It is probably the second oldest profession after prostitution.

What happens here typically in our industry is that we are very much a local based organisation. We can only draw materials in from a relatively small geographical area.

When you say “we can”, is it because of your capacity?

It is not because of our capacity. It is purely down to price. For every W-H company, five miles down the road, there is another company and anther company. It is like a catchment area. It is almost like a cartel how this industry works. We don’t employ sales representatives or purchasing people to go around the UK or even south Yorkshire. We stay very much in this area and if people want to sell to us we will buy from them but people only want to sell to you if you are competitive on price, going to the furthest extreme when we sell our materials you have to think of it as a funnel, you’ve got your metal merchants, you’ve got your engineering, geographically let us say a 5 mile radius, it does go further, but once you start to move further than that, your transportation and labour costs become too excessive, the margins are too tight. When you start to expend more time and more fuel, your driver is taking 3 hours to do a job that would take 30mins (increased variable costs). It does not matter because there are companies closer than us to those clients. We all tend to specialise in different in one area. We might be good at mild steel. There are only two steel mills operating in the UK so we can only sell to two customers. They will only but at a national price. They don’t give us a better price because we are us. They say we are going to pay for instance £100 per tonne.

Even though you operate in a free market paradigm devoid of much regulation and interference in terms of demand and supply of goods, it would seem the market has found a way of regulating itself?

Yes, the market has found a way of regulating itself. I earlier said cartel but this is what I was referring to. Realistically everybody knows everybody. Everybody knows where everybody is buying from; any deviation from the equilibrium price either upwards or downwards has consequences. The only way things change in this industry is if you get unscrupulous people. We’ll take Outokumpu Steel ltd here for example, a multinational company; we deal with this site here and not any of their other sites. It is on a trust basis. If they have material that they want to recycle, we have skips in there. Typical 90% of what we do is with skips, in different sizes. it is machine shop waste, engineer waste, production waste and all metal related waste. You can be talking about something worth a penny per kilo or more or less. The extremes in terms of the quality of the metals are huge. The higher the price per tonne, generally speaking, the smaller the volume. Although Sheffield is a predominantly stainless steel city in terms of engineering and machinery there is still a lot of the a penny per kilo scrap like domestic scrap such as washing machines, cooker and WEEE. There is a high value in WEEE for elements such as gold, silver, rhodium, and a little copper.

A company like ours is a general waste company. We major in metals with licences to do metal recycling to a very high degree. We do not process some of the materials we buy because that is not our skill. Within this pyramid, everybody sells to everyone who are better at what they do than what we are. For example our electronic circuit boards would go to a company specialised in acid etching and recovery of metals by etching physically removing them.

So you have a horizontal relationship within the supply chain with your so-called competitors, recognising better specialism in the supply chain?

Everyone will buy a ten tonne consignment of metals. We will mechanically sort it and use magnets for pulling out steel, iron steel content. Within that you can get some of the stainless steel grades. To identify those, you use electro spectrum-analysis which involves firing x-rays into the material and the electronics analysing the content of the material. It will give you a 90% accurate read out of the metal content of the materials inside. We do a lot of hand and mechanical sorting as well as processing. Sometimes the size of the material we get into our plant is what we call oversize and it means it is not suitable for the recycling industry above us. We buy it as oversize and sell it as oversize and the margin is very small. If we process it to what we call mill-size, the mill being the next recycling process e.g. going straight into an ingot mold and through a furnace and melted into a new ingot again. **(The degree of sorting affects the margin)**. We don't do value-added. The margins are tight. Put us into perspective. Our business is currently around £4-5million turnover. It has been as high as £10 million when commodity prices were high. We didn't handle anymore tonnage. It was just that the value per tonne was greater.

There is this issue that the price of metal scrap is fluctuating?

The price of non-ferrous such as copper, brass, alloys can vary at least 4 times a day. It can go up and down the same day, in one trading session. The London Metals Exchange LME is the world standard on pricing in Dollars. Not only do you have **fluctuation in trading, there are also currency factors and speculators**. Not so long ago when the 2009 financial crisis happened, commodity traders in London, new York and around the world decided they were going to have a go with copper, brass, and nickel alloys and they inflated the prices to draw the materials in a theoretical warehouse, they don't trade anything or move anything, just leave it there and I will tell you when to sell it, push the prices up and sold the materials at a paper profit. A huge profit in fact. They created a vacuum because once the price goes extraordinarily high, we had to find materials to replace the materials we were selling and pay a higher price. When they were identified as being rogue traders, the prices dropped by 50% over night and a lot of people were left with material they had paid a high price for expecting the market to continue and speculators that went in for just three or four months in total and by the time we realised what was happening we were left with material that was drastically over inflated.

Do you think this is the biggest source of uncertainty to your industry; price fluctuation, shocks related to speculation?

The currency shocks are massive especially this year because of Brexit. What we found is that actually the Sterling prices increased. Not only did you have the foreign exchange fluctuation in dollar and euro against sterling but People also started to say ok there is a bit of a problem and I don't want to be in shares in engineering companies anymore. I want to go somewhere safe and somewhere safe is commodities i.e. gold, silver. All those went up a big percentages and it has a knock on effect all the way down the metal market. Copper and brass being the next two to go up as well as nickel alloys. It is a strange market. There is comfort in knowing there are few new starters in the industry. All the people that exist today, certainly the most established ones would be 2nd and 3rd generation businesses. This company is in its third generation started in 1941, registered in 1947 as a limited company. It has been at this site since 1949.

You basically get the scrap for companies, do you ever sell back to such companies after processing, sorting and cleaning?

There is no company that we buy from that then takes reprocessed or sorted material from us. Someone from this funnel effect, there are only so many producers. You can do this for ferrous and non-ferrous. Many people have the material on day one and everybody passes it up line. Eventually someone will process it. In the UK in the Birmingham area we have a lot of brass foundries. In and around Sheffield, we have a lot of ferrous-steel foundries. They will produce the small castings or ingots that will then go into industry for rolling. The smelting company that makes the ingots they then supply to the next company that do the rolling to produce the sheets, tube, bar etc. The outokumpu branch here takes in the bars. The bars, our stainless steel will go to another company who buy from 50 companies for the north of England. Let us say that we do 10 tonnes a day of stainless steel, there are 50 companies and 500 tonnes. That 500 tonnes goes into the steel works and they produce the ingots. They sell the ingot to another company that does the rolling or processing into a sheet, plate or bar. It may be within the same organisation but different areas of the business.

Have you come across Tata steel? They are a good example. Part of their group is Jaguar Cars. They took the decision when they bought the business because they have in their company background the steel business. They decided they were going to make everything from aluminium alloy instead of steel. In their factory in Birmingham area where they are situated now, anything that comes out of what they class as waste stream goes back into their business. Companies like ours would have normally purchased that waste (scrap) stream and supplied it back to them through several layers of trade. They are internalising their waste. They realised if they controlled the raw material going in, they process it into the basic ingot or bar, then they process it through the mills etc. to create the sheet, they can then bang components out of more waste. They are the best example of a circular economy that I know of. Not many others can do that. There are people that make tin cans. We have people in Sheffield that do the 2.5 litre oil drums. They buy cheap steel and put into a machine that rolls the shape and weld the tops and bottoms. Their scrap comes here. The scrap will probably go down to Cardiff, which is where we supply our material to. That is where the steel works are. It is a Spanish company called Salsa. They have steel mills in Germany and Spain. That company makes oil drums. The infrastructure needed for steelmaking is massive.

Why do you have a 5 mile radius on the supply side? Is it applicable to the sales side?

It is a hypothetical 5 mile radius in terms of buying but it is unlimited in terms of sales. A lot of companies bigger than ours are exporting. We chose to supply in the UK. I think we have a stable market. When you got to the export market, it is a bit like the London metal exchange. It is very much driven by successive exchange rates. We are not financially big but we are not taking risks that the dollar is going to drop next month and sell elsewhere outside the UK. A lot of companies look to move the materials they process to china, and India, Pakistan, Bangladesh but it is controlled by a lot of middlemen and speculators.

Do you think it is risk having more people acting as brokers inflating the price?

There is no more material available. It is finite. If we wanted to handle more materials, we have the facilities but the margins are going to be impacted on. We all know the price we can it is the cartel price. EMR are the biggest in England. SIMS is the biggest in the world. They are not governed by the government but by the shares and market. The UK market for metals is £7-8 billion a year. When people try to buy or sell more within the geographical area of UK, it doesn’t make sense because of shipping costs, doubt over the quality of the material, suppliers identity, contaminated material. There are degrees of allowance of non-metallic content and those degrees become smaller and smaller the further you go up the supply chain. Within the industry, companies like SIMS and EMR have invested in machines called fragmentizers. Taking a car as an example, a complete car could go in. the machine destroys it and filters out the various grades of metal or other waste. Plastics, glass, fabrics, wiring, ferrous, non-ferrous metals will be taking away with a magnet. All these things get sorted by a noisy cumbersome expensive machine. We feed that supply because we don’t have the investment and machinery to be able to benefit from the clean waste that comes out of the fragmentiser.

We are a high risk industry. There is always plant moving around, materials being lifted, pulled and processed. There is a lot of thought you have to put into this.

I’ve been talking about engineering companies. Do not forget demolition companies, they will have metals part of their recycling or demolition process. They know it is a commodity and might sell to us to or other bigger players with national contracts. Some companies not like ours might have a demolition department where they have the machinery and expertise to bring down a building and crush aggregates, clean the land and recycle the metal. On the other extreme you have the householder. A lot of general waste companies would put skips in for households, businesses, and local council. We don’t do that. It is too high risk for us. Other companies will put in skips for household waste and recycle everything and we receive the metal waste such as washing machines. Around here we have Mr Rubble, Bradwells, JMS recycling,

For example you were mentioning the so-called tips and the household waste recycling centres operated by the local council, what happens to the metal waste that is collected there?

Whoever is contracted to do the work benefits from the waste. Veolia is the main contractor but not all of them are operated by the local council. We have one close to here, Donald Ward that is independent. They operate the civic amenity side. We don’t handle refrigerators, CFCs, gases. It has to go to a specialist recycler. There is less and less CFCs in industry now e.g. air-conditioning units have less CFCs. In terms of hazardous material in the UK, many items are potentially placed on the restricted list by The Environment Agency such as circuit boards. This becomes restrictive. They are many circuit boards and we don’t think about it. We also don’t process mobile phones and circuit boards. We accumulate, store them and pass them on to specialists. If you try to follow one waste stream from the seller to the user, and the waste stream and goes back into the recycling industry somewhere.

Do you need to be licensed for every waste type in order for you to operate?

The European waste code should be on your licence. That is the current situation. Historically only harmful waste was licenced. The world becomes more and more complicated. There are so many bits of paper, files, fees to pay, reports to do.

Is bureaucracy then the main obstacle to your operations?

There is a lot of European bureaucracy that may settle after Brexit but we don’t know. A lot of it was logical. A lot of it was statistical. The world is changing. The demand for recycling steels will never go away. The demand for iron ore from places like Australia may reduce if we start to produce again. The industry has evolved but not tremendously. It is only when new ideas come to the market; new ways of processing the same material but it's a finite volume. Perhaps a good example to relate to now is the dual fuel cars. There is no waste stream that is really been set up to handle the lithium ion batteries. They are a big problem for the industry going forward. For the last 5 years we have seen two or three cars and we had to reject them because of the very high contaminant possibility for handling the way we normally handle. There is also a risk of high voltage electrocution holding 4-5 thousand volts at a time. Even though the car is not running the battery has stored the power. A normal car on the other hand with a diesel or petrol engine has a 12 volt battery. They are not such an issue. The battery is recycled one way while the engine of the car another. With the lithium battery a whole new industry needs to be set up. It will only set itself up when it is profitable. We need to wait until the volume is higher. 3 cars in 5 years are not enough. As the volume becomes greater, the industry does evolve. But it will only evolve due to finance and not due to initiatives.

Do you think there is a lack of government initiatives in this area promoting this kind of close-loop recycling channels?

It may happen because of Brexit or Donald Trump. It is a more inward looking economy now. It is more globalism.

Is it a paradigm that can be adapted to free market economies like the ones in most of the European countries?

It is one world, one currency. Globalisation has made the world smaller. There are only a few big companies in the world now. Before every district would have its own steelmaking activity and metal merchants, scrap metal dealers, and the rest of it. It has become very much a world player situation. We are quite unique this company and being around for so long, still working this environment with virtually the same companies we were dealing with years ago.

Do you think there will be a concentration effect in the industry?

I don't know. We are very heavily well regulated. There are still too many companies' or organisations outside the regulation that are allowed to exist. It is because example of prosecution might be only £5000. There is an element of grey informal economy within scrap metal market. When we had the cash ban in the UK for buying metals, they didn't do a cash ban for selling metals. The company that we want to buy from, they can find another company that will pay them cash, they are not at fault. It is the company that is giving them cash for the metals that is at fault. There is no enforcement to a high degree. It is good in practice to say no cash but what about selling for cash?

If you are an engineering company, you've got a business producing stainless scrap probably worth a pound per kilo and someone comes up in a white van and says I'll give you £50/kilo, you can have pounds in your pocket, no company tax, and income tax. Nobody regulates you and the guy in the white van. It seems a small element not necessarily stolen metal. The legislation was not new. It was added to existing legislation. It was badly thought through. It had an effect. One which I totally agree with. We don't have to pay cash and choose not to. We could still do it. We lost suppliers. The legislation has affected us and the lack of enforcement of the rules and regulations on that side are disappointing. There is no more material out there, it just goes in circles. Today a company is dealing with us, tomorrow it says it doesn't want to do business with us. Why? We'd rather not say. Everybody knows everybody. It is like a cartel.

Thank you.

Interview with T-H, lawyer, D-P law firm, SCR SUSTAINABILITY LOW CARBON GROUP, Civil society (NGO) and policy stakeholder, 10AM D-P SHEFFIELD, 09/06/2017 1HOUR

Can you give us a bit of background about yourself?

I head the safety, health and environment team group for D-P with around 25 lawyers working in the team who specialise in among other things environmental sustainability, from a legal perspective we provide advice and support to various clients in that arena. We have a climate change consultant that is not yet certified but has consultancy expertise. We are both consultancy and legal. I was an environmental regulator for 12 years and specialised in pollution, health and safety and worked at principle level in local government. For the last 26 years I have worked for D-P piper in environmental and other regulatory areas leading the team and being recognised for environmental excellence. The work we undertake at D-P it is not just legal advice, we also have a consultancy element. We would describe ourselves as trusted business advisers to facilitate educate and assist with environmental compliance and driving sustainability. To support that work ethic, we do a lot of pro-bono work; Putting our time into various ventures for no fee or payment. To promote and initiate sustainability we have been involved in a number of different ventures. The first is the support of the legal sector alliance now called legal sustainability alliance. It was started by D-P to bring law firms together to share best practice in both procurement and their own supply chains on environmental issues, recycling, waste, energy use, minimising of waste etc. Given we are a service provider, we are not on the heavy endo of waste creation or recycling but nevertheless we felt that service industries had a role to play in reducing the carbon footprint of their own organisations and thereby educating their supply chain. The legal sustainability alliance comprises of over a 100 law firms who benefit from sharing best practice on things like waste disposal, printing. We have also been heavily involved in the Sheffield city region sustainability group which I chair. That has been in one form or the other around in she26 years and stared as the south Yorkshire green business club. We support and promote the work of the sustainability partnership, so we can facilitate educate and initiate the take-up of sustainable practice within the region. We have a global sustainability initiative within D-P which I sponsor as the global chair and is aimed at ensuring all of our global office are accredited and awarded ISO14000. Good business sense means good sustainability. I support AREC, local enterprise board representing business for low carbon. We regularly speak at the Castle debates and this year is focused on CE.

Our relationship with the consumer and producer supply chains clearly is through our work as a legal firm. We get access to numerous clients that have sustainability and LCA issues. We work from the intervention of new legislation through to prosecution, and defence and civil claim. We would say cradle to grave in the same way you talk about waste and its disposal. We look at environmental sustainability and those factors within that right from the inception of legislation right through to non-compliance. we have several different lawyers specialising in several different areas who interact on a day to day basis with producers and consumers.

The Sheffield city region sustainability partnership is designed to interact with every stakeholder within the region that is interested in environmental sustainability and that includes NGOs, and local authorities. The board meets at least every 6 weeks and interacts very closely with all of the different formal entities as such as faith groups and individuals that are interested.

How would you define CE?

The idea of a CE is that it does create a more sustainable society. It identifies the benefits of being able to **create a self-sustaining activity** and so therefore any CE has to be self-sustaining. When you look at different elements, for instance the waste aspect you have chosen, because it is circular and not linear, you have the opportunities to have take-offs at various points along that circle but also to keep the momentum within the circle so you can go around the second time.

Sometimes either because of market demand, legislative intervention or regulatory attitude, you may not be able to deal with a particular waste in a particular way. Given a bit of time, you might come around the circle and be able to deal with that waste in a more sustainable way. An example I would give you specifically in relation to metals relates to titanium fines that one of my clients produced. They wanted to go through the transhipment of waste regime which enables you to take waste from one country and export it to another for treatment, recovery and recycling. To move the waste from one country to another you have to go through transhipment rules and one of the rules relates to the environmental impact the waste might have if it escaped from waste custody. The titanium fines were contaminated by engine oil because they had been through a process and the regulators were very reluctant to allow these fines to be shipped to Brazil where they would then be cleaned and used in another process that could deal with the size of the fines that could not be dealt with in the UK. The facility in Brazil could take this metal and use it to produce a product that was capable of distribution within the supply chain. It took six months to convince the regulators that this trans-shipment could handle this particular waste stream. So on day one we had no CE in terms of this waste stream but after six months of persuasion, evidence gathering, debate, dissection of legal principles, it was agreed that the waste could be shipped to Brazil, cleaned and reused in a process with a 100% recovery. That is what I mean with the CE providing the opportunity to temporal or otherwise to continue to look at sustainability because in the linear model, it would have gone most probably to landfill with no recovery whatsoever, or taken longer and cost more. In this example the company owned both businesses and didn’t have the demand to create a second facility in the UK.

What are the challenges faced in the transitioning to circular economy CE? What opportunities would circular economy CE offer the various stakeholders?

I think ***unfamiliarity*** is one. Potentially an initial outlay financial, or time or otherwise which might not be seen as possible in an economic climate that is very tight. So it is sometimes easier not to spend on future interventions because the payback period could affect your bottom-line in a different financial year. It is very important to small firms. They work year to year and don't have 3 year financial plans, they are not big enough. With larger organisations, that is overcome because they can through their 3 year forecasting that spending today will bring about savings in 2-3 years. That is definitely a problem from an SME point of view. I think the opportunities or not so much in **cost savings** that are **inevitable** but in the potential for enterprise and innovation, with other actors. CE has possibilities for job creation and research stimulation. Those for me are the real key. It might not be current stakeholders but people coming into the supply chain. It increases the number of people that are affected.

What do you see as the role of policy makers in this proposed move to CE?

Policy is **hugely important**. **It drives regulatory intervention**. Without the policy, you cannot have the regulation. It is **the foundation block** of the way in which regulation, legislation, and intervention would drive the point. More importantly however than being able to articulate the policy and provide the vehicle for legislative intervention is the desire and ability for it to be enforced. You can make the best law policy in the world but if it you don't have **the means of satisfactory enforcement**; it has no power no teeth. It will not create nor drive change. I see the policymakers having a huge part to play in making sure not only do we have **the legislative framework** to drive change towards a CE but in also producing **the enforcement regime** so that non-compliance can be enforced and thereby driving change.

In your opinion, how eager are stakeholders in the metal industry to embrace the circular economy CE as part of its overall sustainability agenda?

It **depends on the position of a particular entity**. You will have heard of liberty Steel who has taken over Tata steel in Rotherham. They have an agenda for green steel. That absolutely works on the principle of CE in terms of their drive to recirculate heat, reduce heat loss; metal waste etc. the problem with stakeholders in the metals industry is that we are dealing with industries that are hundreds of years old, many with legacy issue since from when they were nationalised and privatised and ***unless you have finances*** available to take you from a 200 year old industry to a that can look at a CE approach, you can never make that move.

I think it is ***not a lack of willingness desire to embrace*** it but a lack of perhaps the ***innovation skills or the finances*** to take them to where they need to be. The metals industry in the UK is under significant pressure in terms of it is bottom-line.

What do you think will be the role of policy post Brexit? So many policies are EU Policies

I think there will be ***little change after Brexit***. We already lead the way on environmental sustainability, clean water and contaminated land. Many of the policies are EU policies but we were instrumental in creating many of those. The one that concerns me is the habitats directive and whether we will be able to produce a policy that protects our environment from a habitat point of view which is absolutely essential from a CE view.

I think to a large extent we have to acknowledge that if we want to trade with Europe we are going to have to comply with EU directives on all products. Whether we have higher standards than Europe is also a concern for industry because we have higher standards on contaminated land than anywhere else. It is not just about adoption of EU standards but will we have our own standards that are more stringent than current EU requirements**. No longer being bound by EU requirements could lead to more stringent domestic standards**.

Can the circular economy work in a free market economy (recalling that all the successful examples - i.e., China - seem to come from centrally planned economies)? Is there a way to "force" markets to converge towards these objectives?

I **don't think there is a way to force markets** to converge. ***The only opportunity for force is through legislative intervention or price-driven incentives***. You cannot force someone to take a price incentive; it would just make no sense not to.one thing we should remember is that once we are away from Europe, **the principle of state aid becomes a nonsense**. We are then able to support our industries in whichever way we like. It is a European level playing field concept in that no state can assist its businesses financially or otherwise to be more efficient, produce cheaper products so they get advantage in the market. If we are not part of the EU we do not have to consider state aid and that might provide incentives to force markets to converge to CE objectives.

I do agree that centrally planned economies could get things done faster but either you legislate to compel markets or you provide incentives. State aid has helped in the planned economies through subsidy and incentive.

Do you think Europe has adopted a reductionist view of Circular economy (just focused on waste recycling, but not involving any rethink of how the economy works)?

I don't think Europe has adopted a reductionist view of Circular economy. I think waste recycling is an obvious starting point. It lends itself to the whole circular idea. Every product we have eventually becomes waste. There are so many waste streams; food waste, pharmaceutical waste, liquid waste etc. it touches and concerns every aspect of what we do. I would agree that they have not expanded their thinking and everyone is very much driven by how much by growth in the economy. The question is how much more growth can we have to be sustainable? It is said that we need growth to survive. An economy has to have growth or there is no economy. How much more growth can we have to be sustainable? And that goes back to one planet living and the use of natural resources. When it comes down to it, it is not about environmental sustainability or climate change, this focuses on natural resources use and recycling of those natural resources. One thing is for sure when we use them we are not getting any more.

Is there then a need for a new economic growth paradigm?

It is not popular view but I can't see how we continue this approach to growth in the economy. There will come a finite point or tipping point.

What role do you see private and public sector having in going towards a more circular society?

I don't see it as being one or the other. I **see it being a combination**. The public was very instrumental in driving the one planet living through the procurement process. It has been able to influence its supply chain by insisting on good environmental credentials etc. public sector is a big purchaser of services and manufacturing and has a huge role to play in driving us towards a more sustainable future. However they cannot do it without private sector investment and attention. It is a partnership. Not the old PPI approach, BUT a true partnership. In essence each doing what they can at different times. They both have a role to play. The private sector needs to see the public sector leading before they traditionally tend to jump on the bandwagon. That might be the case here. Large private sector corporations will jump through hoops for public contracts and in doing so set their management systems and processes to a CE if that's what the public sector demands. Once they have done that it will become business norm and you start to drive CE.

If the transition from LE to CE is to become a success, what/who in your opinion will be responsible in taking the initiatives forward? (Private/public sector?)

They both have a role to play. The private sector needs to see the public sector leading before they traditionally tend to jump on the bandwagon. That might be the case here. it is a collaborative effort.

Do you think concerted and collaborative effort, as well as intensive stakeholder engagement will help the move towards a holistic Circular economy (CE)?

Yes, that is absolutely my point.

Is there anything you would like to add?

I would like to talk about **the educational system**. The School curriculum at an early age allow future leaders to understand the sustainability issues surrounding CE and to let them grow with the ideas that they can stimulate, innovate upon and bring into our future businesses. Once we do that, whilst we might have a generation or two that are not entirely committed, we will start to see the benefits coming through. I think the School curriculum is absolutely essential to all of this.

In my work I will say you have the four levels of competency; the Unconscious incompetent which is the most dangerous type of person you can have, a person who doesn't realise that they are incompetent, then you have conscious incompetent which is a step in the right direction because at least they know they are not very good at something. The conscious competent is the next stage and most people aspire and attain that. You are thinking of sustainability. You are trying to put it into everything you do in a day to day business. You constantly keep refreshing your mind about sustainability. Unconscious competent is the highest accolade. You just do it as a matter of course. You just do business. It is the way you live your life. It's like crossing the road, no one ever thinks about looking both ways, you just do it. Imagine if our school children just did sustainability because that's how life was?

What are your thoughts on Planned obsolescence?

It leads to products that are made not only not to last but not to be adapted. I have a strong view on the indirect carbon footprint. We in the west can claim great advances in our carbon reduction which is part of the CE and waste is part of this. Why? We have shifted the burdens to the east. In the east, countries like China produce all these consumer goods demanded in the west, causing carbon emissions and pollution. Manufacturers have no incentive to produce goods that can be continually updated and refined instead of producing a new one**.** ***Until we get our consumerism habits and product design into sustainability mode***, it will continue not to only have an impact on CE but also impact upon planet and climate change. If you had a basic simple mobile phone that could be upgraded, adapted and refreshed from time to time, we would reduce the degree of production and only need new widgets instead of new phones. **The way manufacturer's drive the desire for new products is a really sticking point.** Legislation cannot help with that. We already have product compliance legislation. Schemes like the producer responsible scheme; where things like the electric equipment is taken back under the WEEE directive, producer responsibility obligations but they still aren't driving the need to stop production, they are creating a take-back scheme so the waste is disposed of properly, but they are not reducing the waste in the first place. It is the reduction in the waste that is very important. These are linear actions. Even legislation can drive the linear approach which isn't ideal. It is better than nothing. It's a good step. A good example is the non-Apple phones that now use standardised chargers**. *Standardisation*** is a start.

Questions about Metals Reverse Supply Chains: For Sheffield city council

Section 1: Basic Information

Name: **A- B**

Department: **Waste Management, Sheffield City Council**

Job Title: **Waste Strategy Officer**

Section 2: Operations

How much waste does the council generate?

Please see https://www.sheffield.gov.uk/environment/waste/ourperformance.html

How much of this waste is metal and WEEE?

See attach spreadsheet for 2015/16

How much waste is being recycled?

Please see https://www.sheffield.gov.uk/environment/waste/ourperformance.html

How much metal waste is being recycled?

See attach spreadsheet for 2015/16

How much could you recycle?

It's not possible to calculate this

How much goes to landfill and incineration?

Please see https://www.sheffield.gov.uk/environment/waste/ourperformance.html

How much metal goes in the black bin? Can this be reduced?

While the Council have looked at the composition of black bins, it's not possible to put a definite figure on this as it will vary, they only way to reduce it is to educate residents.

How do you coordinate waste collection and disposal? who are the key players? What is the waste management structure/hierarchy?

Please see the contract in https://www.sheffield.gov.uk/environment/waste/ourperformance.html

How is waste management funded? Council tax, householders, Government grant, EU?

There is a lot of information available on the internet on this, as an over view Local Authorities are funded by Council Tax and Government grant. Local Authorities are only required to collect domestic waste.

Which obstacles, if any, most affect your operations?

Quite a broad question, current issues are costs and reductions in budget versus customer expectations.

What policies are used to encourage reuse, recycling?

Education is the main tool, again some research will aid in answering this question.

Where do you see the main obstacles that should be tackled to improve waste collection and disposal? (need for more/less legislation, consumer awareness, incentives etc.)

Legislation and the requirements of TEEP in determining how recycling is collected, versus cost of delivering the service. The reduction in budgets hampered by the poor markets for the sale of materials collected.

How many scrap dealers do you have operating within Sheffield?

I don't hold this information, the Environment Agency may be able to help

How do you monitor scrap metal dealers?

The Council does not monitor scrap dealers, it falls to the Environment Agency

Do they (scrap dealers) supplement your efforts to promote recycling and waste reduction?

No

Do you have any reported issues of metal theft?

Question needs to be more specific, I am not aware of any thefts relating to the Councils contract.

What kind of relationship do you have with large metal companies within the Sheffield area to promote reuse and recycling?

We don't have any relationship, Veolia are responsible for arranging all our disposal contracts. Veolia use EMR.

Questions about Metals Reverse Supply Chains: For Wakefield council

Section 1: Basic Information

Name: J-G

Department: Strategic Waste Policy

Job Title: Waste Policy Manager

Years of experience; 23 years

Section 2: Operations

Wakefield District covers some 350 square kilometres and forms one of five Districts which make up West Yorkshire. The District is made up of open, attractive countryside surrounding the main centres of population in the Wakefield City; the five towns of the north east (Pontefract, Castleford, Knottingley, Normanton and Featherstone); Ossett and Horbury in the west, and in the south east Hemsworth and South Elmsall.

How do you coordinate waste collection and disposal?

Wakefield Council has Unitary Authority responsibilities for waste management and thus serves as the Waste Collection Authority (WCA) and Waste Disposal Authority (WDA) simultaneously.

Statutory Responsibilities: As a WCA Wakefield has a duty under Section 45 of the Environmental Protection Act 1990 (EPA 1990) for the kerbside collection of residual, recyclable and if requested, commercial waste for subsequent delivery to a relevant treatment/disposal facility, and a duty under Section 89 of the EPA 1990 to ensure that land under their control is kept free of litter, detritus and refuse. As a WDA Wakefield has a duty under Section 51 of the EPA 1990 for the provision of and management of appropriate facilities. This means the Council or someone acting on behalf of the Council is responsible for providing facilities such as waste disposal points, composting facilities, Household Waste Recycling Centres (HWRCs) and other recycling facilities.

Municipal Solid Waste (MSW) comprises of the following waste types:

- Residual waste collected from households via kerbside collections;
- Recyclates collected from households via kerbside collections;
- Waste arisings handled at the Household Waste Recycling Centres (HWRCs);
- Waste from Bring Sites;
- Bulky waste collections;
- Waste arisings from the collection of street sweepings and litter bins;

- Waste generated under Schedule 2 of the Controlled Waste Regulations 1992 e.g. schools waste;

- Waste arisings from litter bins at municipal parks and gardens;
- Commercial and Industrial (trade) waste collected by the WCA; and
- Clinical waste from domestic and commercial premises.

Wakefield Council - Below figures based on 2015/16 data.								
	Management Type							
	General Waste	Garden	Brick & Rubble	Recycling	Heat to Energy	Other	Total	National Indicator Target
2015/16								
Total municipal waste (incl household waste)	72761	21695	7335	38222	27202	349	167564	40.27%
Percentage of Total Waste	43.42	12.95	4.38	22.81	16.23	0.21	100	

Who are the key players?

The Council remains the main contractor for the collection of waste and recycling from both residential properties as well as commercial properties.

Residual waste

The Council carries out a residual waste collection, emptying a 240 litre bin every fortnight. The Council has a ‘no side waste’ collection policy in force.

Dry recyclable collection

The Council undertakes a fortnightly dry recyclable kerbside collection using a 240 litre bin which collects a range of materials such as glass bottles and jars, plastic bottles and metal cans/tins, paper and cardboard. Additional recyclate side waste is collected.

Garden waste collection

The Council currently undertakes a fortnightly garden waste collection during the summer (March – November) emptying a 240 litre bin.

Bulky waste

Large/bulky items can either be taken to one of the four HWRCs, or a fee-payable collection from the curtilage of the residents’ property is offered and we charge £20 to collect and dispose of a maximum of three bulky items **per collection**. We can visit 3 times in any one day, i.e. for a maximum of 9 items per day (£60). Bulky items

could include fridges, washing machines, cookers and household furniture such as sofas and tables.

Hazardous waste

The Council provides facilities at the HWRCs where householders can deposit a variety of hazardous waste streams such as fluorescent tubes, televisions, paints, engine oil, asbestos, batteries and garden chemicals.

Commercial trade waste

The Council offers a chargeable commercial waste collection service, using a variety of containers from plastic sacks to wheeled bins, euro bins, skips and Rear End Loader skips. Wakefield also operates a commercial mixed recyclable recycling collection scheme.

Waste Disposal function

The management of the Recycling centres, bring sites and the treatment and recycling of municipal waste was outsourced to Shanks Waste Management in 2013. All of the Councils waste is treated and handled by Shanks.

What is the waste management structure/hierarchy?

The collection service management structure has approximately 40 FTEs to manage Streetscene services that includes street cleaning as well as refuse collection, parks, Forestry and Countryside teams. In addition approximately 170 staff are involved in refuse collection, commercial waste collection, clinical and bulky waste collection.

The waste disposal function is now outsourced to Shanks and they employ around 100 staff to manage and deliver the treatment facilities and arrange the disposal of all our waste, as well as the management of the household waste recycling centres.

How is waste management funded? Council tax, householders, Government grant, EU?

Waste management is funded in several ways. Householders currently pay approximately £100 per year as part of their council tax to have their waste and recycling collected, treated and disposed. This payment also covers the cost of providing households with their first set of wheeled bins but does not cover subsequent replacement bins. In addition the Council received a £33 million grant from government that will be spread out and paid over the project term until 2038. The remaining costs are borne by the Council.

Which obstacles, if any, most affect your operations?

Austerity – is the biggest challenge facing local government as there are now insufficient resources to provide services. Services will increasingly be charged for or removed altogether.

Weather can impact on the collection service, however risk assessments dictate how services should be delivered in adverse weather conditions.

Operational reliability can often impact upon operations.

What policies are used to encourage reuse, recycling?

European and national legislation as well as economic drivers are the sole drivers for encouraging recycling. Contractual drivers also encourage and shape operational deliverability. Landfill tax has done its job with diverting waste from landfill.

Where do you see the main obstacles that should be tackled to improve waste collection and disposal? (need for more/less legislation, funding, consumer awareness, incentives etc.)

Harmonisation of collection strategies is a start however it could take 20 years to achieve owing to differing contractual mechanisms that would need to be unpicked. Consumer awareness is key and this comes at a price which many authorities can no longer afford. The principal drivers should now be focused on achieving true value for money and should be based maximising outputs for least financial impact.

What is your experience, interaction of metal recycling of actors such as scrap dealers, environment agency?

We have some direct interaction with the scrap metal industry in relation to offtake contracts for scrap metal from our HWRCs. This is generally a positive relationship, there have been times when this has not been the case when they have wanted to reduce income within a fixed contractual term, we have worked with them when we can. We have had a couple a cases when we have been owed money for commodities this has been withheld and they have then liquidated. The Council has then been unable to recover its income, so we now only allow scrap metal dealers to be one month in arrears.

Our relationship with the local Environment Agency has been generally good. We meet on a quarterly basis to discuss issues across the district and across the waste management facilities.

Appendix D: Interview questions

Introduction

Name? Years of experience?

What is your role within the specific project concerning circular economy and what is your overall role within the organization you are working for?

Circular economy

How do you define circular economy? (In an ideal world, what would the economy and society look like if it was based on a circular economy?)
Would a circular economy create a more sustainable society? Why/ why not?

Metal Stakeholders and circular economy

What role do you see private and public sector having in going towards a more circular society**?**
What actors do you think are needed to implement a circular economy?
Why do you think stakeholders decide to implement circular economy? What drives companies to CE? Is it profit alone?

How aware are the stakeholders of CE? What are you doing to create awareness?

Who is the most dominant stakeholder?

What are the challenges and possibilities/potentials in implementing circular economy in the metals industry?

What are the missing incentives for successful transition to CE?

What challenges or obstacles do you face from other stakeholders in meeting your targets?

Is there a misalignment of motives? Agency problem?

Do motives need to be aligned and converged to avoid prioritisation of one benefit over another (social, environmental and economic?)

Are new skills needed for CE adoption? What new skills are needed for circular economy?

Can the circular economy work in a free market economy (recalling that all the successful examples - i.e., China - seem to come from centrally planned economies)? Is there a way to "force" markets to converge towards these objectives?