The Sustainability of Steel Manufacturing – Liberty Speciality Steels

November 2020

Dr Lucy Smith, The University of Sheffield

This research was funded by the EPRSC Doctoral Prize Fellowship, 2019.

Contents

Foreword

This study was conducted by Dr Lucy Smith for her EPRSC Doctoral Prize Fellowship, Lucy has experience as an Environmental Management practitioner in the steel sector and in later years in her academic career has specialised in Life Cycle Assessment (LCA) work.

The Environment team at Liberty Speciality Steels (LSS) assisted in collecting data for the LCA Study.

This version of the report is non-confidential and the Lifecycle Inventory tables with steel additions and costs have been removed to enable the report to be used by our customers and stakeholders. The results of this report have not been verified by an independent third party.

Edward Heath-Whyte

Head of Environment and Sustainability
Liberty Speciality Steels
February 2021

Executive Summary

The LIBERTY Steel Group is a global business, specialising in the manufacture of virgin and secondary steel to an international customer base. Part of Liberty Steel Group, Liberty Speciality Steels (LSS) is the third largest steel producer in the country, employing 3,000 people across nine sites with an annual rolling capacity of almost three million tonnes [1].

This study was developed as a partnership between LSS and the author to investigate the sustainability impact of four LSS products; 300M Aerospace, Engineering Bright Bar, Leaded Bar, and Leaded Strip. The environmental impacts of each steel product were assessed using Life Cycle Assessment (LCA) and a Social Life Cycle Assessment (SLCA) was used to determine the social impacts relating to steel production at LSS. Due to time constraints, the economic impact of each of the steel products could not be explored in detail and therefore, the author has provided information relating to how this could be performed in the future.

Overall, the results of the LCA show that the 300M Aerospace steel has the highest environmental impact across all of the environmental impact categories studied and the Engineering Bright Bar has the lowest environmental impact. For reference relating to the Global Warming Potential (GWP), the 300M Aerospace steel results in an impact of 1.91 kg CO_2-eq/kg and the Engineering Bright Bar results in an impact of 0.81 kg CO_2-eq/kg.

Social impacts are only slightly related to any technical processes or product under consideration, for example, the social impacts associated with steel production in the UK may be very different to those in China. With this in mind, only one SLCA result is provided in this study which relates to all four of the materials under investigation. The results of the SLCA show that the lowest scoring impact categories are fuel poverty, the Lost Time Injury Frequency Rate (LTIFR), and spending on sports amenities.

This report is the first step in the development of a robust sustainability assessment for steel production by LSS. These results should be treated as a snapshot in time, according to the data provided for 2019. As such, it is good practice for these assessments to be repeated periodically with the aim of achieving continuous improvement.

Introduction

Striking a balance between the aspects of the environment, economy and society, or the "Triple Bottom Line" (TBL), is an underpinning factor of achieving sustainability [2, 3], where a change in one facet may have an effect on one, or both of the other factors [4]. Throughout their life cycle, manufactured products affect all three pillars of sustainability, from the extraction of raw materials, the manufacturing process, logistics, use and end of life management. Despite this, research has shown that it is during the product design phase where around 80% of the sustainability impacts are determined [5].

In the past, decision making in the manufacturing sector has centred around economic and technical issues; more recently the environmental impacts of manufacturing have been considered but social aspects, in the main, continue to be overlooked [6]. This can be attributed to challenges relating to the range of concepts in the social dimension, how to apply them and the relevant measurement methodology [6].

Steel manufacturing continues to be essential globally, despite its high contribution to global carbon emissions [7]. Steel production relies on the material's inherent recyclability; 100% of steel can be recycled to an identical, higher, or lower grade material [8]. Steel scrap is the primary material input in the Electric Arc Furnace (EAF) steel production route [9] and when compared with other steel manufacturing routes (e.g., blast furnace or open hearth furnace), manufacturing steel using an EAF offers the advantages of energy reduction and reduced direct CO_2 emissions [10, 11].

Published research relating to steel sustainability is extensive. In their review of sustainability assessments, Long et al. [3] emphasise that methodologies may be too industry specific, focus heavily on stakeholders or include a plethora of indicators and therefore are not directly applicable to the iron and steel industry [3]. Therefore, the team used selection criteria to determine relevant economic indicators according to the Chinese Ministry of Finance's Enterprise rules and Chinese and other Asian literature, social indicators were modified from [12, 13] and the chosen environmental sub-groups were based around investment in pollution control and environmental protection, emissions, and energy consumption [3].

Arena and Azzone [14] adapted the Global Reporting Initiative by identifying indicators relevant to the steel industry and using expert opinion to ensure that their chosen indicators were measurable. A total of 36 key sustainability indicators were proposed and then each mapped against five steel production routes; blast furnace – basic oxygen furnace, EAF, hot rolling, mechanical processing, and coating [14].

Singh et al. [15] developed the composite sustainability performance index (CSPI) to assess the sustainability performance specifically in the steel sector using a simple, quantitative methodology. The team enlisted the help of experts to determine key sustainability indicators; five economic indicators, fifteen environmental indicators, and fourteen societal indicators were identified which were accompanied by a further twelve organisational governance indicators and 14 indicators relating to technical aspects [15]. The use of a composite indicator allows a large amount of data to be condensed into a manageable system for interpretation by a range of stakeholders [15].

Strezov et al. [16] assessed the sustainability of iron and steel production within the context of sustainable development, defined with respect to "the consumption needs for water, land and energy, and emission rates of greenhouse gases and priority pollutants to the atmosphere, relative to the industrial economic input". Therefore, the team assessed production according to energy consumption, greenhouse gases, other key air pollutants and key metal emissions, water consumption and, land use. When the results were normalised against the value of the dollar for steel products, EAF production was ranked higher than direct reduced iron processing and basic oxygen steel making [16].

Annual, voluntary reporting of eight sustainability indicators is required as part of the "Steel Sustainability Champions Recognition Programme" for worldsteel members [17]. Four environmental performance indicators, two social performance indicators, and two economic performance indicators are published on the worldsteel website [18] and in the "Sustainable Steel" publication [19]. The aim of the indicators is to present a standardised methodology for measuring sustainability with respect to the association's sustainable development policy [18]. As the data is trended over time, this provides stakeholders with a clear understanding of how the industry is performing year on year.

BS 8905:2011 [4] concerns the determination of the sustainability of a material through the completion of a life cycle assessment (LCA) to determine the environmental impacts of the material, a life cycle costing (LCC) to understand the economic impacts of the material, and a social life cycle assessment (SLCA) to consider the social aspects of the material. This methodology is commonly referred to as a life cycle sustainability assessment (LCSA), the methodology of which is based around a broader and deeper LCA [20].

Specifically, WorldSteel provide benchmark LCA data for their members, as shown here in Figure 1. This data is an average of all EAF slab manufacturing within each region and an average of all EAF slab manufacturing within LSS. The results show that, on average, EAF slab manufacturing by LSS has a lower GWP (0.62 kg CO_2-eq) than the four regions assessed. This result is slightly lower than that of the average EAF slab manufacturing in Europe (0.65 kg CO_2- eq) and significantly lower than that of Russia (1.42 kg CO_2-eq).

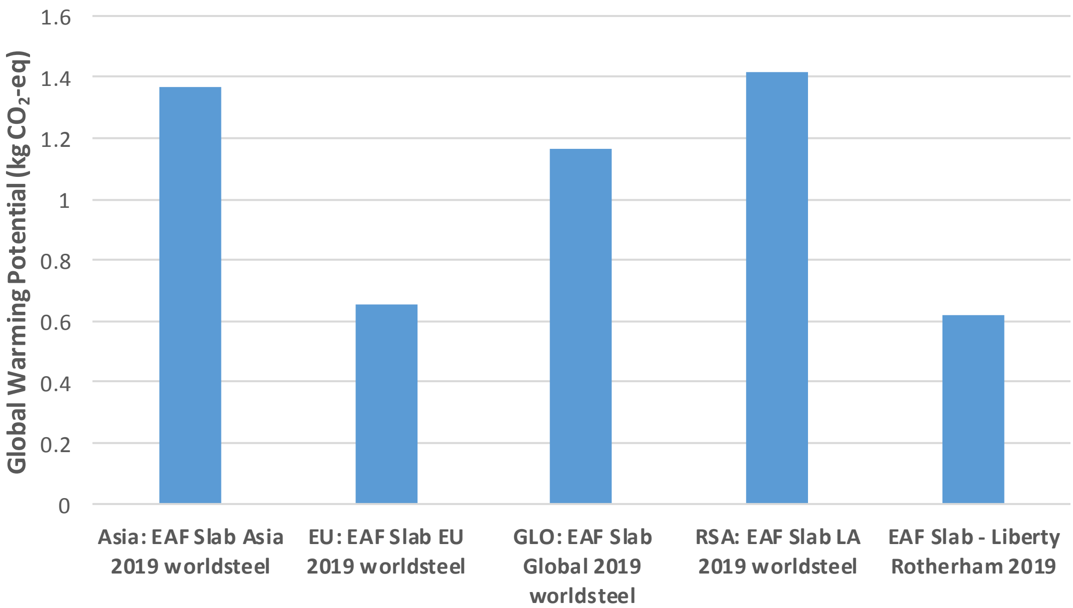

Figure 1: The average Global Warming Potential (GWP) of EAF slab production in Asia, Europe, Globally, Russia and Liberty Rotherham. Provided by Worldsteel.

This study specifically considers the environmental and social impacts of four LSS products; 300M Aerospace, Engineering Bright Bar, Leaded Bar and Leaded Strip. Additionally, the social and economic impacts are also explored. The methodologies employed to develop a robust life cycle assessment

(LCA) and a social life cycle assessment (SLCA) are provided in the "Methodology" section. The "Results and Discussion" section provides the results and in-depth discussion of the LCA and SLCA, furthermore, details relating to the requirements for LCC are also discussed. A "Conclusion" is provided which outlines the main findings and potential studies that could be undertaken to enhance and support these findings. The appendix of this document includes the Life Cycle Inventories (LCIs) and emission intensities utilised for the LCA.

Methodology

Life Cycle Assessment

LCA is a principal means of determining and enhancing the process industry's environmental impact [21] and is governed by the requirements of BS EN ISO 14040:2006 [22]. Four steps must be followed in the completion of the LCA; (i) goal and scope definition; (ii) inventory analysis; (iii) impact assessment and (iv) interpretation [22].

In line with the requirements of BS ISO 20915:2018, Life cycle inventory calculation methodology for steel products [23], the goal of this study is to determine the environmental impacts of 1kg of steel manufactured in the Electric Arc Furnace by LSS. As such, the relevant functional unit was 1kg of manufactured steel (a mass based functional unit [23]) and the LCA was applied according to the system boundary (the scope) identified in Figure 2. Four steel types were assessed: 300M Aerospace, Engineering Bright Bar, Leaded Bar, and Leaded Strip. Data for the LCIs of each product were collected by a local representative of LSS and all inputs were converted to the functional unit (1kg of steel manufactured) to enable a comparison of the four products to be made. To ensure that a representative sample for each steel type was assessed the inputs were calculated as the average input over five representative manufacturing runs during 2019; the LCIs for each steel type can be found in Tables 5 – 8. The process route diagrams of each steel product are shown in Figures 3 – 5.

Scrap allocation in the LCI should "*align to the goal and scope of the study*" [23] and therefore the LCI of steel can be handled in a number of different ways. The Worldsteel Association LCI methodology [24] accounts for the utilisation of steel scrap for steel making and provides a system to allocate "credits" for recycling steel at end-of-life. Following a discussion with a WorldSteel representative, it was deemed that this methodology does not lend itself well to the EAF process. Therefore, this study utilises the "cut off system model" where primary production of the material is allocated to the primary user, not the secondary user [25]; the use of this methodology was supported by the aforementioned worldsteel representative. Therefore, as required by BS ISO 20915:2018, no burdens were assigned to the scrap inputs and consequently no credits were applied to the steel recycling [23].

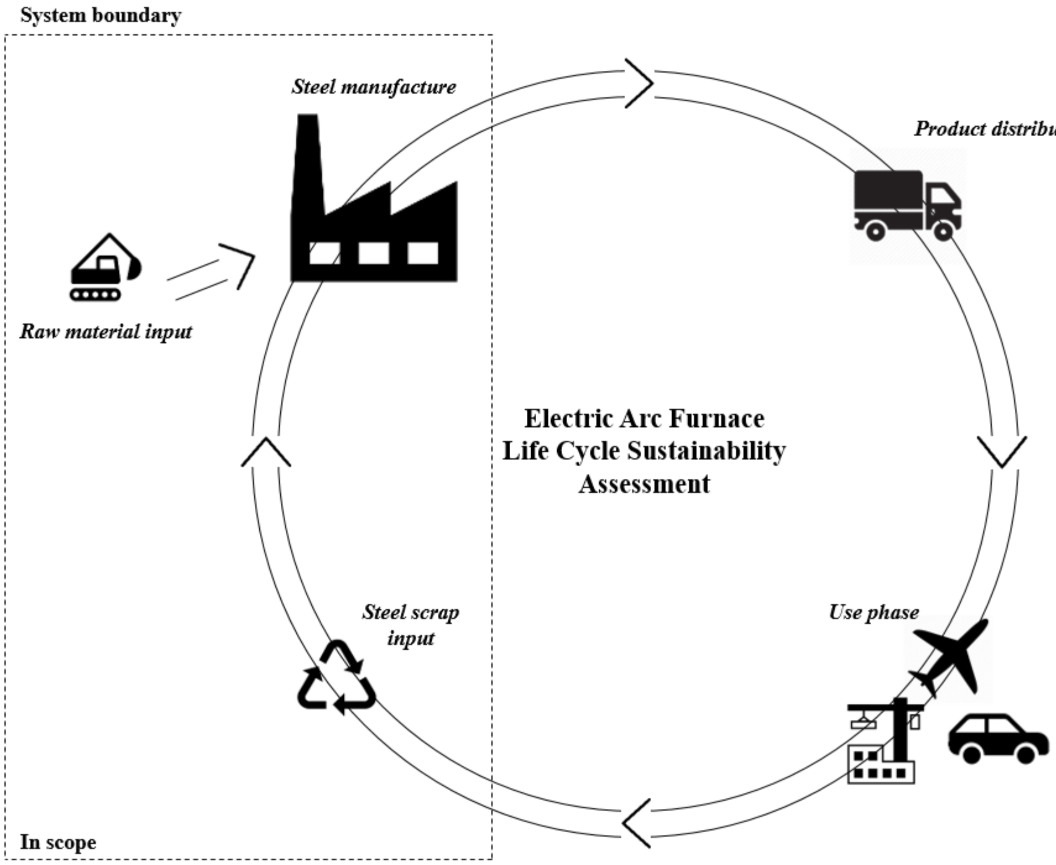

Figure 2: System boundary applied to the life cycle assessment of Liberty Speciality Steels steelmaking (Rotherham, Brinsworth, Stocksbridge, and Wednesbury) for four steel types; 300M Aerospace, Engineering Bright Bar, Leaded Bar, and Leaded Strip, from cradle-to-gate incorporating raw materials and energy inputs, primary material production and the manufacturing process.

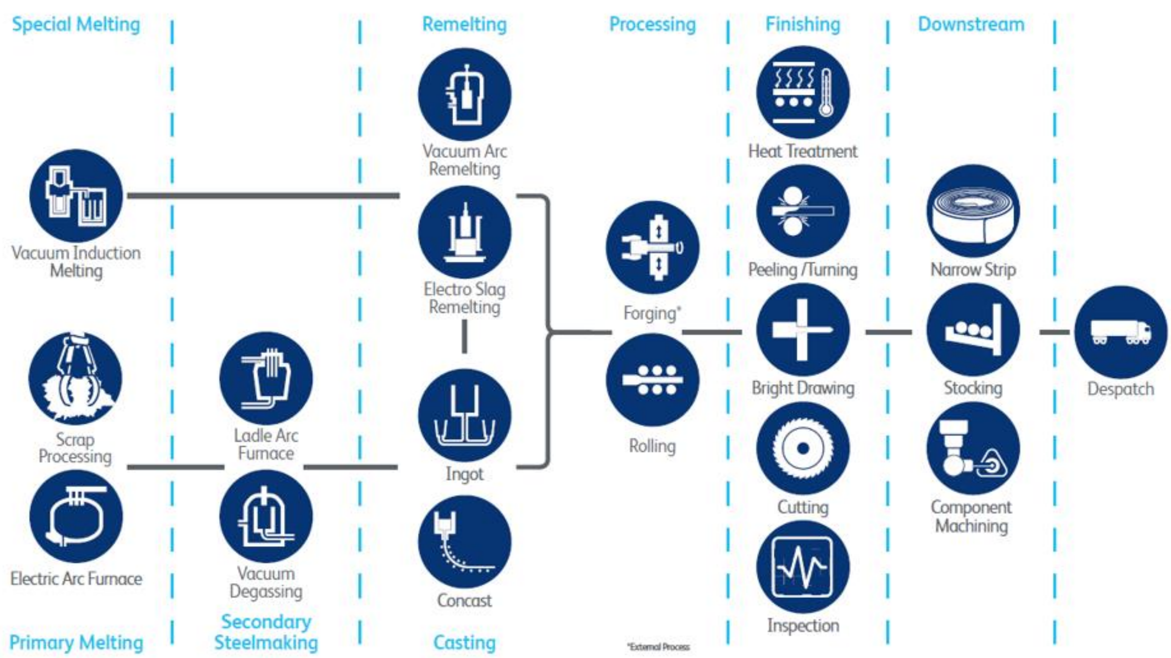

Figure 3: Aerospace 300M steel process route diagram.

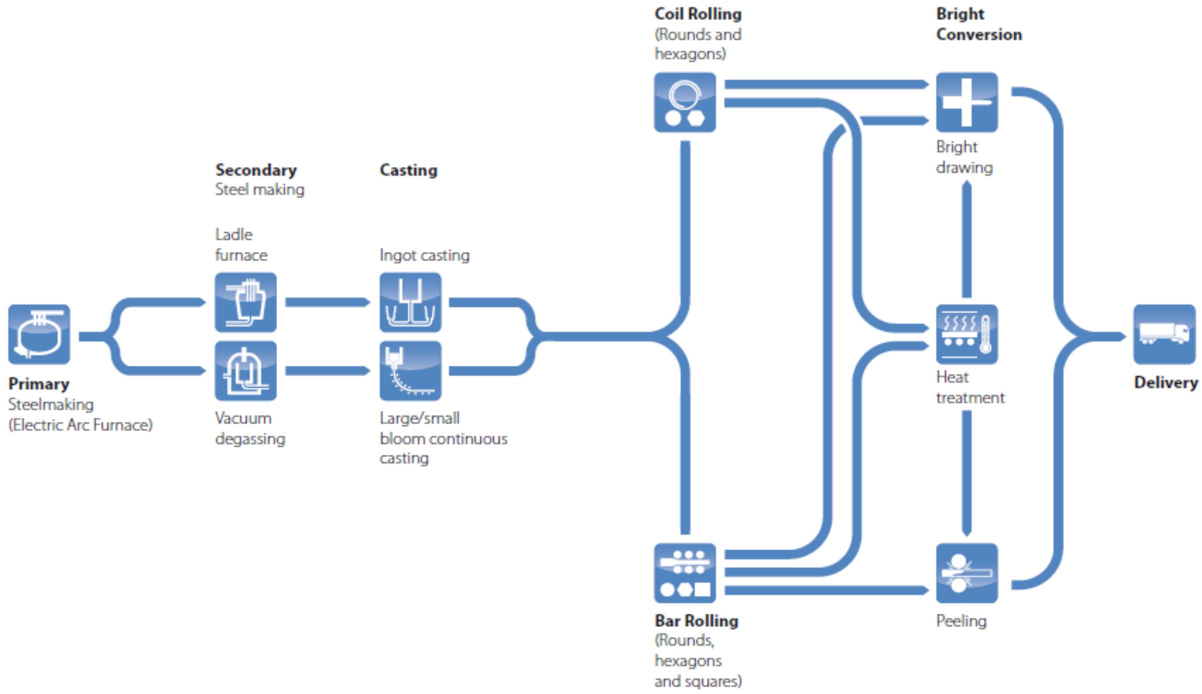

Figure 4: Engineering Bar and Leaded Bar steel process route diagram.

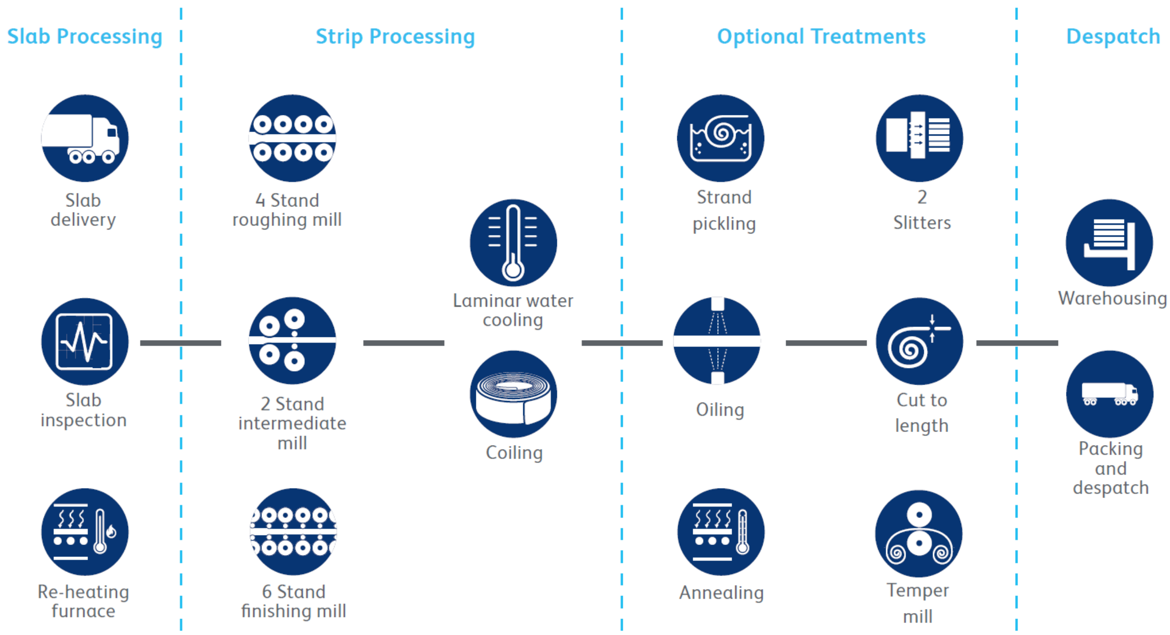

Figure 5: Leaded Strip steel process route diagram.

Environmental impact categories derived from the ReCiPe Midpoint (H) v1.13 and cumulative energy demand impact assessment methodologies, taken from the Ecoinvent database [25], were utilised in this study. The ReCiPe methodology uses characterisation factors to transform the extraction of natural resources and emissions into environmental impacts. Midpoint level characterisation factors occur along the pathway of the impact and relate strongly to environmental flows with inherently low uncertainty. The hierarchist approach was chosen for this assessment as it corresponds with the scientifically accepted time span and impact mechanisms [26]. Each of the environmental impact categories utilised in this study are outlined below and in Table 1.

The Global Warming Potential (GWP) calculates the change in the earth's temperature following the emissions of greenhouse gases over a given 100-year time horizon and is measured as tonnes or kg CO_2-equivalent (eq). The Freshwater Ecotoxicity Potential (FETPinft), Human Toxicity Potential (HTPinf), Marine Ecotoxicity Potential (METPinft) and Terrestrial Ecotoxicity Potential (TETPinft) relate to the toxicity impact of a given input and measure the emissions of 1,4-Dicholorobenzene eq to freshwater, urban air, seawater and industrial soil, respectively. Eutrophication concerns the accumulation of chemical nutrients in ecosystems which ultimately leads to the disproportionate growth of plant life thereby reducing the quality of the water and the populations of animals. The marine eutrophication potential (MEP) is expressed as kg N-eq and the freshwater eutrophication potential (FEP) is expressed as kg P-eq as nitrates, nitrogen oxide and phosphorous all have an adverse effect on eutrophication. Acid rain is formed when acidic gases react with water in the atmosphere; the terrestrial acidification potential (TAP), measured as kg SO_2-eq, accounts for the impact caused by these reactions. The depletion of the ozone layer, caused by the emission of CFCs, halons and HCFCs, is measured by the Ozone Depletion Potential (ODP) and expressed as kg CFC-11-eq [27, 28]. The Cumulative Energy Demand (CED) or embodied energy, calculates the primary energy accumulated during the life cycle of a product, [29] it is measured in MJ-eq and is calculated as the sum of untransformed energy sources e.g. fossil fuels [30]. The impact categories, their abbreviation, unit and life cycle inventory analysis (LCIA) method are summarised in Table 1.

Table 1: List of the environmental impact categories, their corresponding units and LCIA methodologies used in this study.

Environmental impact category	Abbreviation	Unit	LCIA Method
Global warming potential	GWP100	kg CO_2-eq	ReCiPe Midpoint (H) v1.13
Freshwater ecotoxicity potential	FETPinf	kg 1,4-DCB-eq	
Human toxicity potential	HTPinf	kg 1,4-DCB-eq	
Marine ecotoxicity potential	METPinf	kg 1,4-DCB-eq	
Terrestrial ecotoxicity potential	TETPinf	kg 1,4-DCB-eq	
Freshwater eutrophication	FEP	kg P-eq	
Marine eutrophication	MEP	kg N-eq	
Ozone Depletion Potential	ODP	kg CFC-11-eq	
Terrestrial acidification potential	TAP100	kg SO_2-eq	
Cumulative energy demand	CED	MJ-eq	Cumulative energy demand

Where emissions data within the Ecoinvent database could not be sourced, data points were calculated using guidelines based around stoichiometric reactions or, if necessary, material substitutions were made according to similar functionalities or chemical characteristics [31].

Equation 1 allows for the chosen environmental impacts categories (Table 1) to be attributed to each input provided by the LCI (Tables 5 – 8) [30].

$$Process\ LCA = \sum_{i=1}^{n} A_{p(i)} \times E_{p(i)} \tag{1}$$

The supply chain inputs (*i*) are denoted by *Ap*, as per the constraints of the system boundary shown in Figure 2. *n* signifies the total number of inputs (*i*) and the emission intensity of the environmental impact categories (Table 1) are given by *Ep* for each input (*i*) into the supply chain [30]. The emission intensity of each input is provided in Table 9.

Social Life Cycle Assessment

In this study, the SLCA methodology developed by Singh and Gupta [32] was utilised. The pair split the chosen indicators into three groups, all of which are outlined in Table 2; Group 1 consists of those indicators soured from national databases, the indicators in Group 2 relate to management level socio-economic conditions, and the Group 3 indicators relate to the documentation of policies and processes, how they are deployed, monitored, and reviewed [32].

It was deemed that the "access to resources" indicators chosen by Singh and Gupta [32] were unsuitable for this study and therefore were substituted for "fuel poverty", measured but the proportion of households in fuel poverty (%). Fuel poverty statistics for England [33] were utilised to attribute a score to this indicator, this information is shown in Table 2. Since the publication of Singh and Gupta's [32] methodology, the "health index", provided by the Human Development Index, has been made obsolete. Therefore, in this study, the "Life Expectancy Index" was used which utilises the same methodology (life expectancy (years) using a minimum value of 20 years and a maximum value of 85 years). Finally, it was deemed appropriate to provide a score of 4 for "Ratio of female to male entry-level worker wages" when a ratio of 1 is achieved.

As social issues are only marginally related to the technical processes under consideration [34], only one SLCA result is provided in this study which relates to all four of the materials under investigation. Data was collected from publicly available databases to gather the results of the Group 1 indicators, specifically for the UK; the results of the indicators in Groups 2 and 3 were sourced directly from the industry case study. The results are shown in Table 4.

Table 2: Assessment criteria for the Social Life Cycle Assessment.

Group	Impact indicator		Assessment criteria and score			
			1	2	3	4
1	Fuel poverty		>10%	>5 - 10%	>0 - 5%	0%
	Education index [35]		<0.49	0.5 – 0.6	0.6 – 0.7	>0.71
	Life Expectancy Index*		<0.49	0.5 – 0.6	0.6 – 0.7	>0.71
	Mortality rate*		>6	4 - 6	2 - 4	<2
	Income Index		<0.24	0.25 – 0.35	0.36 – 0.48	>0.49
2	**Impact indicator**	**Assessment criteria**	**1**	**2**	**3**	**4**
	Employees receiving minimum wage	Percentage of employees receiving minimum wage	<50%	50 – 75%	75 – 90%	>90%
	Lost time injury frequency rate (LTIFR)	LTIFR = (Lost time injuries / Total man hours worked) x 1,000,000	>2	0.2 - 5	0.1 – 0.5	<0.1
	Discrimination on wage	Ratio of female to male entry-level worker wages	<0.7	0.7 – 0.8	0.8 - <1	1
	Support to local suppliers	Percent of spending of annual budget on local suppliers	<40%	40 – 50%	50 – 60%	>60%
	Sustainability/ environmental reporting	Level of disclosure and reporting	<50%	50 – 75%	75 – 90%	>90%
3	**Impact indicator**		**1**	**2**	**3**	**4**
	Child labour risk		Documented policy without processes, lacking deployment, no monitoring or review.	Documented policy, processes, partial deployment but no monitoring and review.	Documented policy, processes, visible deployment, partial monitoring and review.	Documented policy, processes, visible deployment, robust monitoring and review.
	Forced labour risk					
	Human rights complaints					
	Complaints by communities					
	Spending on cultural activities					
	Spending on sports amenities					
	Skill development					
	Local employment created					
	Incidents of corruption					
	Anti-competitive risk					
	Customer satisfaction					
	Incidents of consumer health and safety					

Results and Discussion

Life Cycle Assessment

The results of the LCA are shown in Table 3 and in Figures 6 – 9. Overall, the product with the highest environmental impact across all of the environmental impact categories studied is the 300M Aerospace steel. Although each individual input into the supply chain has an associated environmental burden, it is key to highlight the "hotspots" within the system (those inputs with the highest impact) to ensure that mitigation strategies can be implemented that result in the highest reduction in the total impact. As such, it is the use of the iron-molybdenum alloy and nickel in the 300M Aerospace steel structure and the electricity requirements of the manufacturing processes that result in the overriding percentage contribution to the environmental impact categories studied.

The iron-molybdenum alloy has the highest percentage contribution to the FETP (78.8%), HTP (67.5%), METP (77.8%), FEP (70%) and MEP (33.7%) impact categories. Molybdenum is a necessary element for animals and plants with relatively low toxicity [36], despite this high intake has been found to lead to copper deficiencies therefore affecting the toxicological impact categories [37]. The release of nitrogen oxide from the refinery and other industrial processes required for iron-molybdenum production contributes to the high MEP result and phosphorous emissions from industrial sources are present in wastewater emissions, therefore contributing to the FEP result [38]. The use of nickel in this steel structure has the highest environmental contribution to the TETP (44.1%) and TAP (67.1%) impact categories. The impact of nickel mining has resulted in severe local implications such as acid rain (TAP) due to SO2 emissions, the acidification of wetlands and soil contamination. Furthermore, biodiversity has reduced and the human population are at risk of lung and nose cancers [39, 40]. Finally, the electricity use during the manufacturing process has the highest percentage contribution to the GWP (52.6%), ODP (67.5%) and CED (63.5%) impact categories, this impact is discussed in more detail below.

Comparatively, the environmental impacts of the Engineering Bright Bar, Leaded Bar and Leaded Strip are dominated by the electricity requirements of the manufacturing processes and the use of electrodes in the manufacturing process. In all three cases, the highest contributor to the GWP, MEP, ODP, TAP and CED impact categories is electricity and the use of electrodes has the highest impact on the FETP, HTP, METP and TETP. The FEP impact category has a slightly higher percentage contribution from electricity for the Leaded Bar, whilst the Engineering Bright Bar and Leaded Strip have a show a higher percentage contribution from the use of electrodes.

As mentioned above, the EAF manufacturing process results in lower energy use and lower direct CO_2 emissions when compared with other steel manufacturing routes (e.g. blast furnace or open hearth furnace) and therefore inherently results in a lower environmental impact [10, 11]. Despite this, the steel industry continues to be a significant contributor to the UKs industrial emissions and as such efficient decarbonisation strategies are required to enable the UK to achieve net-zero greenhouse gas emissions by 2050 [41]. Strategies include the use of carbon capture and storage/utilisation as an end-of-pipe retrofitted solution to ensure the direct capture of emissions from combustible gases [42].

This study uses the Great Britain, electricity, medium voltage [kWh] dataset from Ecoinvent to attribute the impact of electricity use during the steel manufacturing process [25]. This impact could be reduced through the use of local renewable energy sources e.g. on-site wind turbines or solar panels [43], or by sourcing electricity from "green" energy suppliers.

Table 3: The results of the Life Cycle Assessment for each environmental impact category, as outlined in Table 1.

Product	Environmental impact category									
	GWP	FETP	HTP	METP	TETP	FEP	MEP	ODP	TAP	CED
	kg CO_2-eq/kg	kg 1,4-DCB-eq/kg				kg P-eq/kg	kg N-eq/kg	kg CFC-11-eq/kg	kg SO_2-eq/kg	MJ-eq/kg
300M Aerospace	1.91	1.29	3.57	1.13	3.91E-04	2.79E-03	6.64E-04	2.15E-07	0.02	48.40
Engineering Bright Bar	0.81	0.09	0.61	0.08	9.15E-05	3.46E-04	1.56E-04	1.01E-07	3.27E-03	21.20
Leaded Bar	1.04	0.09	0.64	0.08	9.82E-05	3.82E-04	1.85E-04	1.29E-07	3.76E-03	27.41
Leaded Strip	1.10	0.09	0.66	0.08	1.37E-04	3.99E-04	1.95E-04	1.47E-07	3.91E-03	30.41

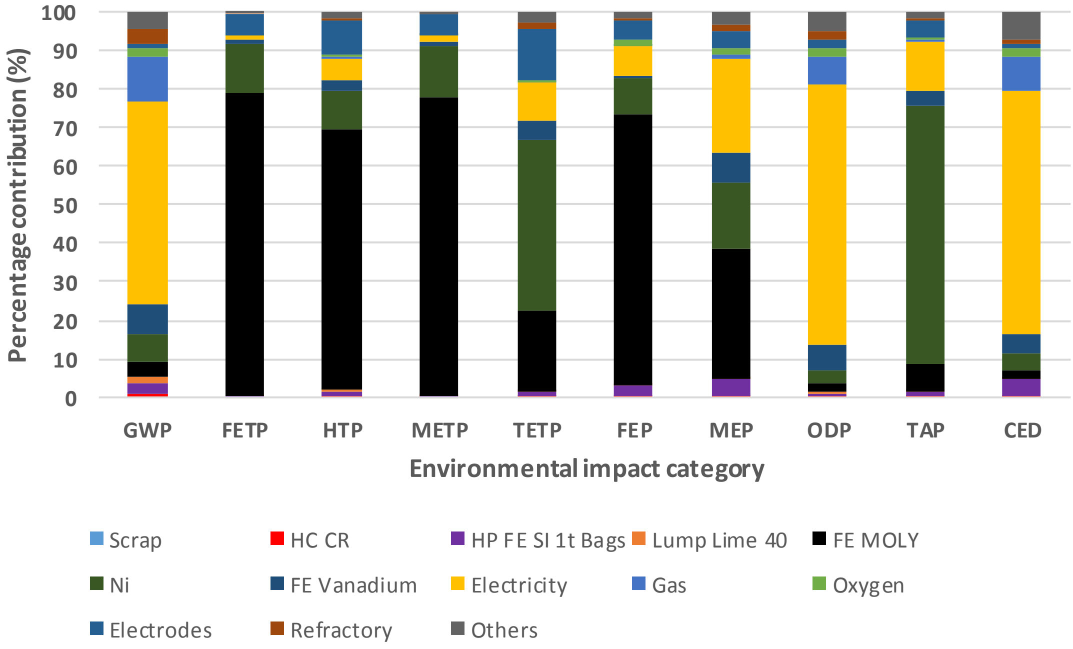

Figure 6: The percentage contribution of each supply chain input to manufacture the 300M Aerospace steel, according to each of the environmental impact categories studied as outlined in Table 1. N.B. "Others" refers to those inputs contributing to less than 1% of the total of the GWP indicator.

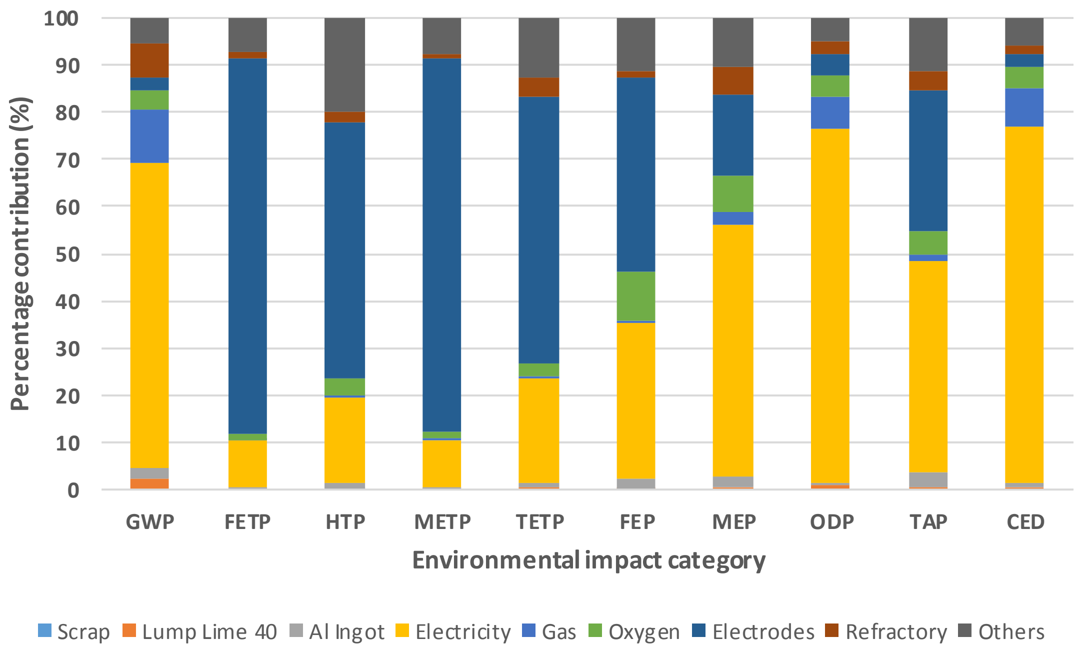

Figure 7: The percentage contribution of each supply chain input to manufacture the Engineering Bright Bar, according to each of the environmental impact categories studied as outlined in Table 1. N.B. "Others" refers to those inputs contributing to less than 1% of the total of the GWP indicator.

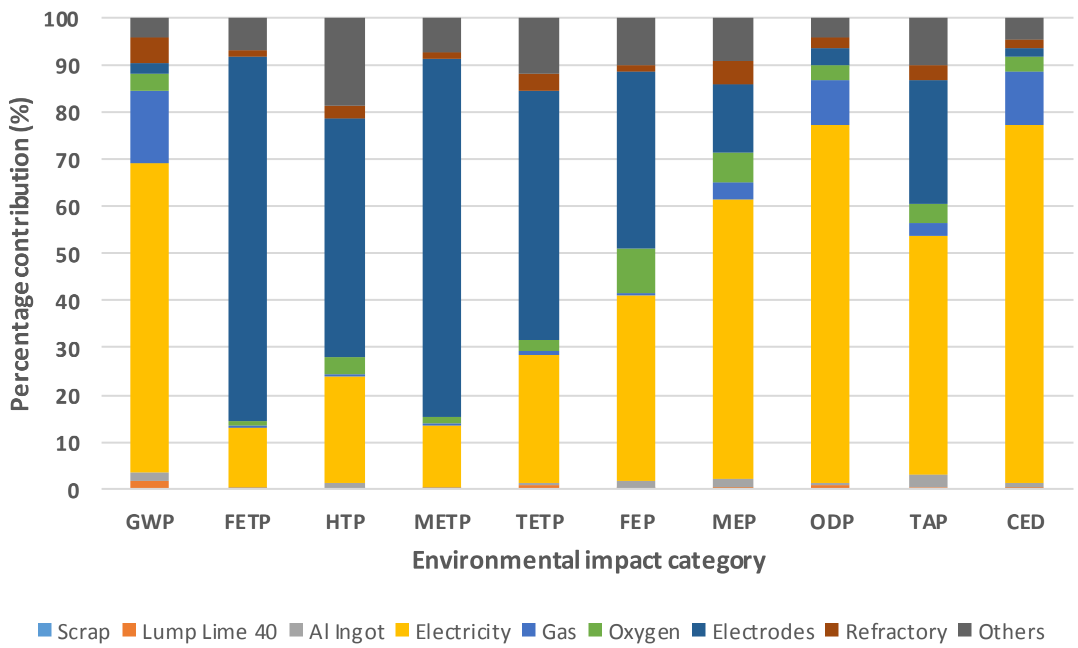

Figure 8: The percentage contribution of each supply chain input to manufacture the Leaded Bar, according to each of the environmental impact categories studied as outlined in Table 1. N.B. "Others" refers to those inputs contributing to less than 1% of the total of the GWP indicator.

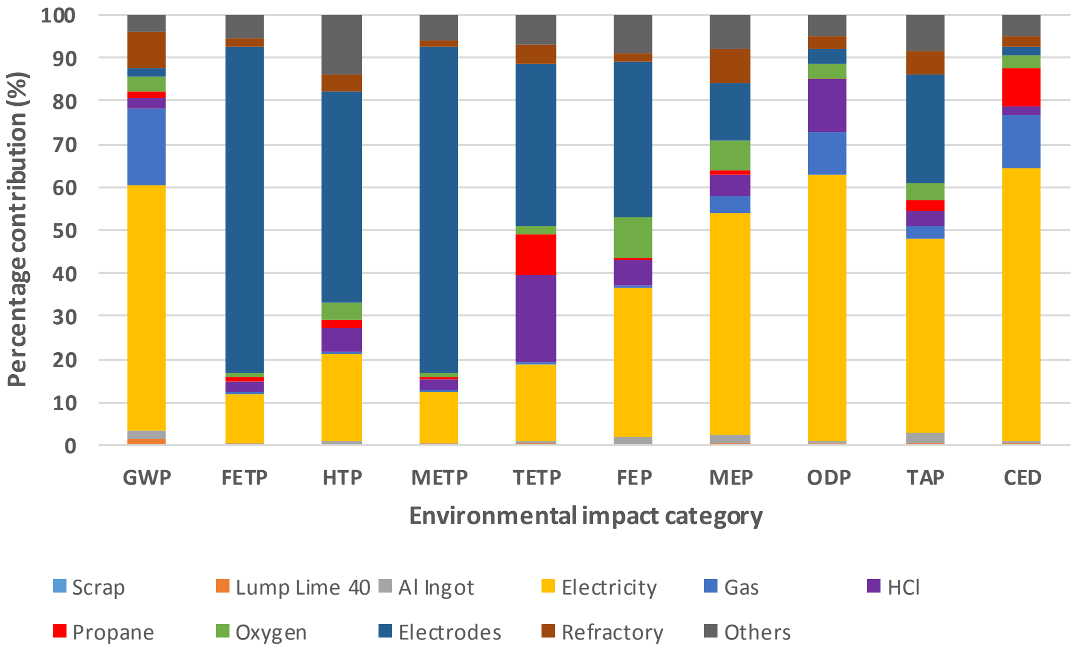

Figure 9: The percentage contribution of each supply chain input to manufacture the Leaded Strip, according to each of the environmental impact categories studied as outlined in Table 1. N.B. "Others" refers to those inputs contributing to less than 1% of the total of the GWP indicator.

The electrodes are manufactured from premium petroleum needle coke, coal tar pitch, and additives and are consumed within the EAF process at a rate between 1.8 and 9.9 kg/t of liquid steel [44]. To manufacture petroleum coke, through the carbonisation of bituminous coal, results in the emission of particulate matter, nitric oxides, sulphur dioxide, aromatic compounds and trace metals. These emissions contribute to the results of the environmental impact categories outlined above. Furthermore, when petroleum coke itself is heated, this also results in the emissions of volatiles like hydrocarbons which have carcinogenic properties [45]. Therefore, to mitigate the environmental impacts posed by the electrodes in the EAF, the rate of consumption should be optimised as far as possible.

Overall, the results presented here are much higher than those provided in Figure 1 for the EAF Slab produced at LSS. This difference may be due to a difference in the system boundaries applied to the two studies or it may simply be that EAF Slab has a much lower environmental impact than the four products considered in this study.

Social Life Cycle Assessment

The results of the SLCA are shown in Table 4. The lowest score in Group 1 can be attributed to "Fuel poverty" though it must be acknowledged that LSS do not have direct influence over the results of any of the Group 1 indicators. These are national level indicators that are updated on an annual basis (approximately). LSS can use the sources provided to monitor this data moving forward. Despite this, LSS do have direct impact on the results of Groups 2 and 3 and while the majority of the Group 2 indicators score 4, the LTIFR scores 1 and spending on sports amenities scores 2.

Table 4: Results of the Social Life Cycle Assessment.

<table>
<tr><th>Group</th><th colspan="2">Impact indicator</th><th>Result</th><th>Score</th><th>Source</th></tr>
<tr><td rowspan="5">1</td><td colspan="2">Fuel poverty</td><td>10.3</td><td>1</td><td>[33]</td></tr>
<tr><td colspan="2">Education index</td><td>0.9</td><td>4</td><td rowspan="4">[35]</td></tr>
<tr><td colspan="2">Life Expectancy Index*</td><td>0.9</td><td>4</td></tr>
<tr><td colspan="2">Mortality rate*</td><td>3.7</td><td>3</td></tr>
<tr><td colspan="2">Income Index</td><td>0.9</td><td>4</td></tr>
<tr><td rowspan="6">2</td><td>Impact indicator</td><td>Assessment criteria</td><td>Result</td><td>Score</td><td>Source</td></tr>
<tr><td>Employees receiving minimum wage</td><td>Percentage of employees receiving minimum wage</td><td>100%</td><td>4</td><td rowspan="5">LSS</td></tr>
<tr><td>Lost time injury frequency rate (LTIFR)</td><td>LTIFR = (Lost time injuries / Total man hours worked) x 1,000,000</td><td>6</td><td>1</td></tr>
<tr><td>Discrimination on wage</td><td>Ratio of female to male entry-level worker wages</td><td>1</td><td>4</td></tr>
<tr><td>Support to local suppliers</td><td>Percent of spending of annual budget on local suppliers</td><td>0.7</td><td>4</td></tr>
<tr><td>Sustainability/ environmental reporting</td><td>Level of disclosure and reporting</td><td>100%</td><td>4</td></tr>
<tr><td rowspan="14">3</td><td colspan="2">Impact indicator</td><td>Score</td><td colspan="2">LSS Source</td></tr>
<tr><td colspan="2">Child labour risk</td><td>3</td><td colspan="2" rowspan="3">Procurement Policy
Modern Slavery Statement
Skills cast legal training</td></tr>
<tr><td colspan="2">Forced labour risk</td><td>3</td></tr>
<tr><td colspan="2">Human rights complaints</td><td>3</td></tr>
<tr><td colspan="2">Complaints by communities</td><td>4</td><td colspan="2">Environmental incidents - documented, reported and reviewed by senior leaders.</td></tr>
<tr><td colspan="2">Spending on cultural activities</td><td>3</td><td colspan="2">Sustainability Policy</td></tr>
<tr><td colspan="2">Spending on sports amenities</td><td>2</td><td colspan="2">2 Officers for Roundwood Sports and Social club. Maintenance support also provided.</td></tr>
<tr><td colspan="2">Skill development</td><td>4</td><td colspan="2" rowspan="2">Sustainability Policy</td></tr>
<tr><td colspan="2">Local employment created</td><td>4</td></tr>
<tr><td colspan="2">Incidents of corruption</td><td>3</td><td colspan="2">Anti-bribery Policy inc. test</td></tr>
<tr><td colspan="2">Anti-competitive risk</td><td>3</td><td colspan="2">Code of conduct. Competition law training on skills cast</td></tr>
<tr><td colspan="2">Customer satisfaction</td><td>4</td><td colspan="2">Quality Control Work Instructions.
LSS Product Quality Complaint Process.
Quality Control Procedure.</td></tr>
<tr><td colspan="2">Incidents of consumer health and safety</td><td>3</td><td colspan="2">Sustainability Policy.
REACH statements.
Safety Data Sheets.</td></tr>
</table>

With respect to the LTIFR, Health and Safety is of paramount importance within LSS, data is monitored daily and reported throughout the company to promote safe working practices. All sites operate health and safety management systems. ISO 45001 is held by Rotherham melting shop and bar mill, this management system promotes continuous improvement, improved employee safety, a reduction in workplace risks and safer working conditions [46]. The system is audited by an externally accredited auditor. This serves as a means to reduce the LTIFR and therefore increase the score associated with it in the SLCA.

While LSS provide two Officers for Roundwood Sports and Social club and maintenance support, this procedure is not monitored and reviewed. To ensure that all of the Group 3 social indicators score 4 points, each impact should have a documented policy and associated processes which are visibly deployed with a robust monitoring and review system [32].

Life Cycle Costing

Life cycle costing (LCC) was not conducted during this study due to time constraints. LCC is a tool for economic analysis that determines the costs and/or benefits of an investment throughout its life cycle [47]. Generic guides to LCC are provided by BS 3811, BS 3843, and PAS 55. BS 8905:2011 [4] provides details with respect to the LCC of a material throughout its life cycle. These costs include:

- Financial costs
- Environmental and social costs
- Planning, design, construction, and acquisition costs
- Operation and maintenance costs
- Renewal, rehabilitation, replacement, or disposal costs
- Depreciation
- Cost of finance

LCC should be conducted in-line with the system boundary provided in Figure 2 to provide a robust and coherent economic assessment [48].

Conclusion

This report provides a robust and up-to-date Life Cycle Assessment for four Liberty Speciality Steels (LSS) steel products and a Social Life Cycle Assessment (SLCA) for steel production in the Rotherham manufacturing plant. Overall, the 300M Aerospace steel has the highest environmental impact across all of the environmental impact categories analysed. The “hotspots” in this supply chain relate to the use of the iron-molybdenum alloy and nickel in the structure of the steel and the electricity requirements for manufacture. Of the remaining three steel products analysed, the Engineering Bright Bar has the lowest environmental impact across those environmental impact categories studied. The results show that this steel and the Leaded Bar and Strip have the same “hotspots” within the supply chain; the electrodes consumed by the EAF and the electricity utilised in the manufacturing process.

Those social “hotspots” that can directly be affected by LSS relate to the LTIFR and spending on sports amenities. Despite this, the policies surrounding all social aspects should be reviewed to ensure that they are robust and managed appropriately to increase the overall score of the SLCA.

If a robust Life Cycle Costing (LCC) were conducted it would be possible to adopt the methodology outlined in BS 8905:2011, Framework for the assessment of the sustainable use of materials – Guidance, to determine a single sustainability score for each of the materials analysed in this research. Though the absence of an LCC does not diminish the findings of this report; the results can be used as a starting point to implement mitigation strategies to reduce the environmental and social impacts of LSS and the methodology can be replicated to determine the environmental impacts of other products and the future environmental and social impacts of the products studied in this research.

Appendix

Lifecycle Inventories

This version of the report does not have the lifecycle inventories as they contain confidential information.

Emission intensities

Table 9: The emission intensities of each environmental impact category for each supply chain input, provided by the Ecoinvent database.

Input	**Ecoinvent database name**	**Environmental impact category**									
		GWP	**FETP**	**HTP**	**METP**	**TETP**	**FEP**	**MEP**	**ODP**	**TAP**	**CED**
		kg CO_2-eq	kg 1,4-DCB-eq				kg P-eq	kg N-eq	kg CFC-11-eq	kg SO_2-eq	MJ-eq
General steel scrap	N/A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Anthracite	hard coal mine operation and hard coal preparation, [kg] Europe, without Russia and Turkey	0.33	0.01	0.28	0.01	1.05E-05	3.67E-04	8.73E-05	3.44E-09	1.50E-04	31.01
AL Wire/ Ingot	aluminium production, primary, ingot, [kg], RoW	18.99	0.29	6.42	0.27	6.36E-04	0.01	3.54E-03	6.00E-07	0.10	214.06
HC CR	ferrochromium production, high carbon, 55% Cr, [kg], RoW	4.39	0.16	1.23	0.17	3.83E-04	1.74E-03	7.10E-04	1.29E-07	0.01	52.55
HP FE SI 1t Bags/ Low AL FE SI	ferrosilicon production,[kg], RoW	3.01	0.09	3.19	0.09	2.09E-04	4.71E-03	1.54E-03	8.47E-08	0.02	111.89
Carbon 99/ INJ Carbon TFN	carbon black production, [kg], RoW	1.80	0.03	0.22	0.03	9.38E-05	1.23E-04	1.69E-04	9.60E-07	0.01	80.42
Lump lime 40	quicklime production, in pieces, loose, [kg], RoW	1.16	1.15E-03	0.04	1.64E-03	3.74E-05	2.36E-05	3.50E-05	5.68E-08	1.10E-03	5.35
TOPEX	Calculated	0.69	0.02	0.27	0.02	2.69E-05	6.30E-05	1.05E-04	1.09E-08	8.71E-04	1.90
MN Metal	manganese production, [kg], RER	2.47	0.40	2.48	0.38	2.60E-04	2.24E-03	1.04E-03	2.51E-07	0.02	56.34
FE Moly	Calculated	52.98	791.69	1873.05	680.80	0.06	1.52	0.17	3.20E-06	1.19	851.85

NI	nickel mine operation, sulfidic ore, nickel, 99.5%, [kg], GLO	14.10	15.74	35.91	14.62	0.02	0.03	0.01	7.70E-07	1.50	192.36
FE V	Calculated	229.82	19.59	136.91	17.33	0.03	0.03	0.08	2.13E-05	1.51	3752.64
HSV SS 1000kg	Calculated	1.01	0.01	0.22	0.01	4.04E-05	1.11E-04	7.06E-05	9.25E-08	1.67E-03	6.91
Sulphur Wire/ Rock Sulphur	sulfur production, petroleum refinery operation, [kg], Europe without Switzerland	0.14	1.60E-04	0.01	2.87E-04	1.67E-05	1.27E-06	8.79E-06	2.47E-08	0.02	2.05
Lead shot	primary lead production from concentrate, [kg], GLO	1.94	0.67	24.17	0.59	2.40E-03	2.74E-03	9.54E-04	1.33E-07	0.04	25.50
MC/HC/SI MN	ferromanganese production, high-coal, 74.5% Mn, [kg], RER	0.82	0.24	1.42	0.23	1.06E-04	9.69E-04	5.01E-04	9.96E-08	0.01	21.78
NDS9 1100kg	Calculated	0.86	0.01	0.15	0.01	3.16E-05	5.76E-05	6.13E-05	5.10E-08	1.12E-03	4.40
FE Phos	Calculated	0.30	0.01	0.18	0.01	1.04E-04	2.78E-04	1.11E-04	3.64E-08	1.35E-03	7.27
Electricity	market for electricity, medium voltage, [kWh], GB	0.37	0.01	0.08	0.01	1.45E-05	8.19E-05	5.97E-05	5.37E-08	1.04E-03	11.40
Gas	heat and power co-generation, natural gas, conventional power plant, 100MW electrical, [MJ], GB	0.02	6.86E-05	3.86E-04	7.73E-05	1.21E-07	2.32E-07	8.99E-07	1.71E-09	1.36E-05	0.44
Nitrogen	air separation, cryogenic, nitrogen, liquid, [kg], RER	0.23	0.01	0.16	0.01	1.37E-05	2.36E-04	7.89E-05	2.96E-08	9.97E-04	6.02
Propane	natural gas production, propane, [kg], RER	0.40	0.02	0.32	0.01	3.18E-04	2.33E-05	4.53E-05	1.11E-08	2.36E-03	65.18
Argon	argon production, liquid, [kg], RER	1.46	0.04	0.98	0.04	8.65E-05	1.48E-03	4.97E-04	1.87E-07	0.01	38.13
Oxygen	market for oxygen, liquid, [kg], RER	0.59	0.02	0.39	0.02	3.61E-05	5.96E-04	2.00E-04	7.52E-08	2.53E-03	15.25

Electrodes	anode production, graphite, for lithium-ion battery, [kg], RoW	5.52	18.17	82.35	16.01	0.01	0.04	0.01	1.17E-06	0.25	132.98
Oil & Grease	lubricating oil production, [kg], RER	1.19	0.05	0.47	0.05	1.97E-04	4.16E-04	2.37E-04	6.23E-07	0.01	66.88
Towns water	tap water production, conventional treatment, [kg], Europe without Switzerland	2.65E-04	9.66E-06	1.71E-04	8.84E-06	2.35E-08	2.34E-07	8.73E-08	3.36E-11	1.34E-06	6.26E-03
River water	tap water production, underground water without treatment, [kg], Europe without Switzerland	1.71E-04	5.46E-06	1.15E-04	5.01E-06	1.12E-08	1.71E-07	5.81E-08	2.16E-11	7.44E-07	4.34E-03
Refractory	refractory production, basic, packed, [kg], RoW	1.77	0.03	0.47	0.03	1.12E-04	1.51E-04	2.94E-04	8.41E-08	3.92E-03	14.67

References

[1] *Liberty Steel UK*. Available: https://libertysteel.co.uk/

[2] J. Elkington, "Partnerships from cannibals with forks: The triple bottom line of 21st-century business," *Environmental Quality Management,* vol. 8, pp. 37-51, 1998.

[3] Y. Long, J. Pan, S. Farooq, and H. Boer, "A sustainability assessment system for Chinese iron and steel firms," *Journal of Cleaner Production,* vol. 125, pp. 133-144, 2016.

[4] B. S. I. B. 8905:2011, "BS 8905:2011, "Framework for the assessment of the sustainable use of materials. Guidance"," 2011.

[5] S. Ahmad, K. Y. Wong, M. L. Tseng, and W. P. Wong, "Sustainable product design and development: A review of tools, applications and research prospects," *Resources, Conservation and Recycling,* vol. 132, pp. 49-61, 2018/05/01/ 2018.

[6] J. W. Sutherland, J. S. Richter, M. J. Hutchins, D. Dornfeld, R. Dzombak, J. Mangold*, et al.*, "The role of manufacturing in affecting the social dimension of sustainability," *CIRP Annals,* vol. 65, pp. 689-712, 2016/01/01/ 2016.

[7] D. Santos and R. Lane, "A material lens on socio-technical transitions: The case of steel in Australian buildings," *Geoforum,* vol. 82, pp. 40-50, 2017/06/01/ 2017.

[8] C. Broadbent, "Steel's recyclability: demonstrating the benefits of recycling steel to achieve a circular economy," *The International Journal of Life Cycle Assessment,* vol. 21, pp. 1658-1665, 2016/11/01 2016.

[9] D. Burchart-Korol, "Life cycle assessment of steel production in Poland: a case study," *Journal of Cleaner Production,* vol. 54, pp. 235-243, 2013/09/01/ 2013.

[10] W. Jaimes and S. Maroufi, "Sustainability in steelmaking," *Current Opinion in Green and Sustainable Chemistry,* vol. 24, pp. 42-47, 2020/08/01/ 2020.

[11] A. Hasanbeigi, M. Arens, J. C. R. Cardenas, L. Price, and R. Triolo, "Comparison of carbon dioxide emissions intensity of steel production in China, Germany, Mexico, and the United States," *Resources, Conservation and Recycling,* vol. 113, pp. 127-139, 2016/10/01/ 2016.

[12] F. Székely and M. Knirsch, "Responsible Leadership and Corporate Social Responsibility:: Metrics for Sustainable Performance," *European Management Journal,* vol. 23, pp. 628-647, 2005.

[13] Y. Xiao, "Comprehensive Performance Appraisal of Steel Enterprises in Low-carbon Economy Background," Central South University of Forestry and Technology, China, 2010.

[14] M. Arena and G. Azzone, "Process based approach to select key sustainability indicators for steel companies," *Ironmaking & Steelmaking,* vol. 37, pp. 437-444, 2010.

[15] R. K. Singh, H. R. Murty, S. K. Gupta, and A. K. Dikshit, "Development of composite sustainability performance index for steel industry," *Ecological Indicators,* vol. 7, pp. 565-588, 2007.

[16] V. Strezov, A. Evans, and T. Evans, "Defining sustainability indicators of iron and steel production," *Journal of Cleaner Production,* vol. 51, pp. 66-70, 2013/07/15/ 2013.

[17] "Sustainability Indicators Data Reporting, User Guide," 2019.

[18] W. S. Association. (2020). *Worldsteel sustainability indicators*. Available: https://www.worldsteel.org/media-centre/press-releases/2019/sustainable-steel-indicators-2019.html

[19] "Sustainable Steel Indicators 2019 and the steel supply chain," worldsteel association.

[20] N. Onat, M. Kucukvar, A. Halog, and S. Cloutier, "Systems Thinking for Life Cycle Sustainability Assessment: A Review of Recent Developments, Applications, and Future Perspectives," *Sustainability,* vol. 9, p. 706, 2017.

[21] X. Jia, D. C. Y. Foo, R. R. Tan, and Z. Li, "Sustainable development paths for resource-constrained process industries," *Resources, Conservation and Recycling,* vol. 119, pp. 1-3, 2017/04/01/ 2017.

[22] I. O. f. Standardization, "ISO 14040:2006, "Environmental Management - Life cycle assessment - Principles and framework"," ed, 2006.
[23] "BS 20915."
[24] W. Association, "Life Cycle Inventory Methodology Report," 2017.
[25] Ecoinvent. (http://www.ecoinvent.org/ accessed 19/09/2017, 17th May 2018). Available: http://www.ecoinvent.org/
[26] M. A. J. Huijbregts, "ReCiPe 2016 v1.1: A harmonized life cycle impact assessment method at midpoint and endpoint level Report I: Characterization," National Institute for Public Health and Environment2017.
[27] A. P. Acero, C. Rodriguez, and A. Ciroth. (29th May 2018). *Green Delta*. Available: http://www.openlca.org/wp-content/uploads/2016/08/LCIA-METHODS-v.1.5.5.pdf
[28] CML2001. *think step GaBi*. Available: http://www.gabi-software.com/international/support/gabi/gabi-lcia-documentation/cml-2001/
[29] M. A. J. Huijbregts, L. J. A. Rombouts, S. Hellweg, R. Frischknecht, A. J. Hendriks, D. van de Meent*, et al.*, "Is Cumulative Fossil Energy Demand a Useful Indicator for the Environmental Performance of Products?," *Environmental Science & Technology,* vol. 40, pp. 641-648, 2006/02/01 2006.
[30] T. Ibn-Mohammed, L. S. C. Koh, I. M. Reaney, A. Acquaye, D. Wang, S. Taylor*, et al.*, "Integrated Hybrid Life Cycle Assessment and Supply Chain Environmental Profile Evaluations of Lead-based (Lead Zirconate Titanate) versus Lead-free (Potassium Sodium Niobate) Piezoelectric Ceramics," *Energy & Environmental Science,* vol. 9, pp. 3495-3520, 2016.
[31] G. Geisler, T. B. Hofstetter, and K. Hungerbühler, "Production of fine and speciality chemicals: procedure for the estimation of LCIs," *The International Journal of Life Cycle Assessment,* vol. 9, pp. 101-113, 2004.
[32] R. K. Singh and U. Gupta, "Social life cycle assessment in Indian steel sector: a case study," *The International Journal of Life Cycle Assessment,* vol. 23, pp. 921-939, April 01 2018.
[33] E. I. S. Department for Business, "Annual Fuel Poverty Statistics in England, 2020 (2018 data)," 2020.
[34] A. Jørgensen, L. C. Dreyer, and A. Wangel, "Addressing the effect of social life cycle assessments," *The International Journal of Life Cycle Assessment,* vol. 17, pp. 828-839, 2012.
[35] (19/04/17). *Human Develipment Index (HDI)*. Available: http://hdr.undp.org/en/content/human-development-index-hdi
[36] D. G. Barceloux and D. Barceloux, "Molybdenum," *Journal of Toxicology: Clinical Toxicology,* vol. 37, pp. 231-237, 1999/01/01 1999.
[37] G. M. Ward, "Molybdenum Toxicity and Hypocuprosis in Ruminants: A Review," *Journal of Animal Science,* vol. 46, pp. 1078-1085, 1978.
[38] E. Report, "Source apportionment of nitrogen and phosphorus inputs into the aquatic environment No 7/2005."
[39] G. M. Mudd, "Global trends and environmental issues in nickel mining: Sulfides versus laterites," *Ore Geology Reviews,* vol. 38, pp. 9-26, 2010.
[40] A. Anttila, E. Pukkala, A. Aitio, T. Rantanen, and S. Karjalainen, "Update of cancer incidence among workers at a copper/nickel smelter and nickel refinery," *International Archives of Occupational and Environmental Health,* vol. 71, pp. 245-250, 1998.
[41] BEIS, "2018 UK Greenhouse Gas Emissions, Final figures," 2020.
[42] S. Tian, J. Jiang, Z. Zhang, and V. Manovic, "Inherent potential of steelmaking to contribute to decarbonisation targets via industrial carbon capture and storage," *Nature Communications,* vol. 9, p. 4422, 2018/10/24 2018.
[43] I. Staffell, "Measuring the progress and impacts of decarbonising British electricity," *Energy Policy,* vol. 102, pp. 463-475, 2017/03/01/ 2017.

[44] A. Babich and D. Senk, "Chapter 12 - Coal use in iron and steel metallurgy," in *The Coal Handbook: Towards Cleaner Production*. vol. 2, D. Osborne, Ed., ed: Woodhead Publishing, 2013, pp. 267-311.

[45] S. K. Ramaiah and H. M. Mehendale, "Coke Oven Emissions," in *Encyclopedia of Toxicology (Second Edition)*, P. Wexler, Ed., ed New York: Elsevier, 2005, pp. 635-637.

[46] "ISO 45001."

[47] J. H. Miah, S. C. L. Koh, and D. Stone, "A hybridised framework combining integrated methods for environmental Life Cycle Assessment and Life Cycle Costing," *Journal of Cleaner Production,* vol. 168, pp. 846-866, 2017.

[48] W. Kloepffer, "Life cycle sustainability assessment of products," *The International Journal of Life Cycle Assessment,* vol. 13, p. 89, 2008.

Author: Dr Lucy Smith