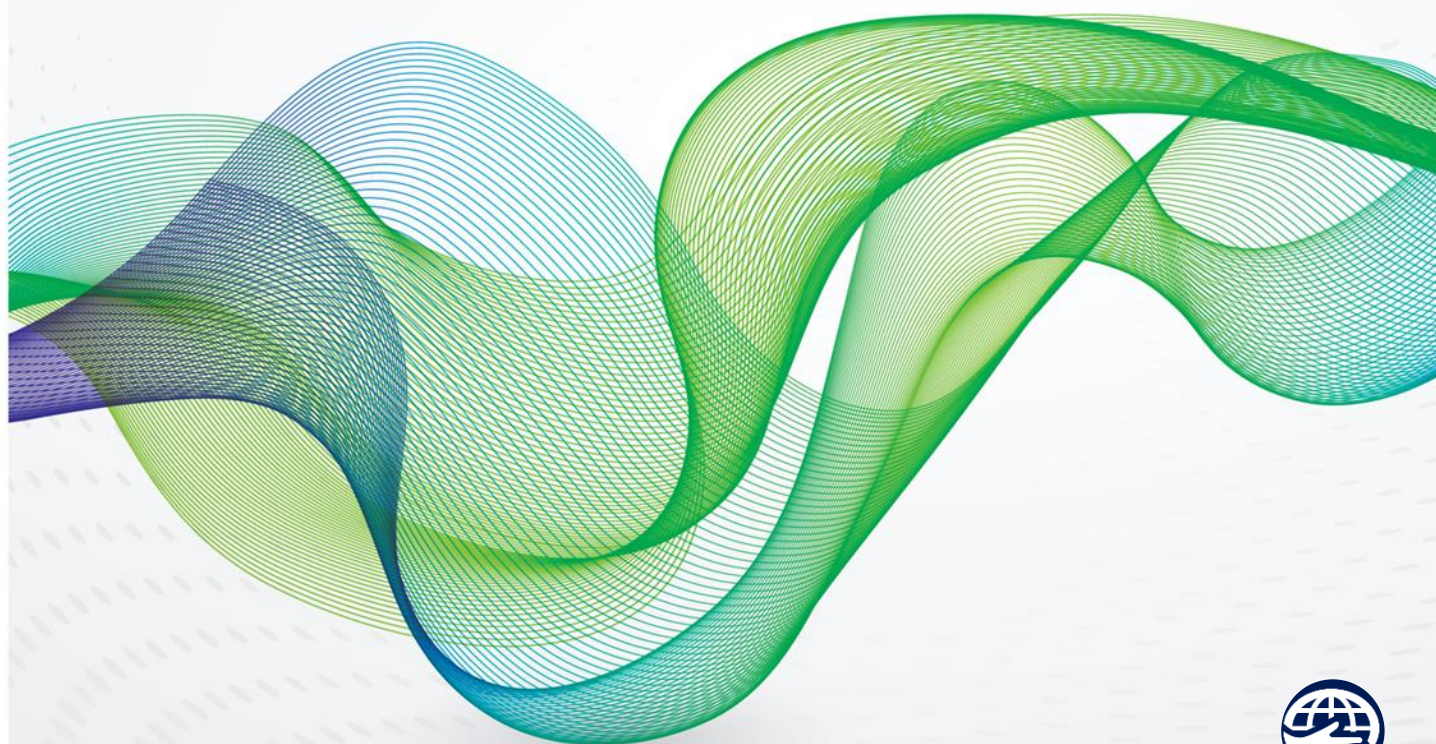




THE OXFORD
INSTITUTE
FOR ENERGY
STUDIES

March 2022

Steeling the race: 'Green steel' as the new clean material in the automotive sector



ENERGY TRANSITION

OIES PAPER: ET 09

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ISBN 978-1-78467-196-9



Acknowledgements

The authors appreciate the financial support from the BHP Industry Carbon Dioxide Capture Project at the University of Edinburgh without which this work could not have been undertaken. Thanks also to David Billedeau at the University of Waterloo, Canada, for his valuable comments and suggestions.



Abstract

This paper aims to examine consumer behaviour towards, and the willingness to adopt, 'green steel' in the automotive sector. Semi-structured interviews were held with experts from global, regional and country-specific industry associations and automakers. This paper appraises potential demand for green steel within different vehicle types (based both on size and powertrain) and shows that manufacturers of electric heavy-duty vehicles are most likely to be the first adopters of green steel. A case for green advanced higher-strength steels (AHSS) can also be made in light-duty passenger vehicles, which may mitigate competition from alternative lightweight materials in terms of cost and greenness (depending on source and utilization regions). This work emphasizes a need to revisit current CO₂ performance regulations, engage in educational green marketing campaigns, and explore innovative market-based mechanisms to bridge the gap between relatively-low carbon abatement costs of steelmaking and high abatement costs of vehicle manufacturing.



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1. Introduction

Green product development, through innovative product design, is a key strategy in addressing environmental sustainability concerns and has received growing attention from governments, industries and consumers globally (Pujari, 2006; Dangelico et al., 2017). Green product development has been portrayed as a win-win concept for having a lower environmental impact while remaining competitive (Elkington, 1994; Porter and Van der Linde, 1995). The term 'green', however, is problematic. The concept and its boundaries are poorly defined leading to a variety of uses and misuses of the term in both academia and industry (Durif et al., 2010). In this paper, a green product is defined as one with minimal-to-no carbon footprint (i.e. low GHG emissions) throughout its lifecycle. The literature on green products and their development in different sectors is vast, and is often grounded in the emerging notions of circular economies and sustainable business models (Rizos et al., 2016; Blomsma and Brennan, 2017; Kirchherr et al., 2017) green marketing (Boztepe, 2012; Chan et al., 2012; Katsikeas et al., 2016), and sustainable supply chain management (Green et al., 2012; Ying and Li-jun, 2012; Ahi & Searcy, 2013).

Green product development has also been prescribed as a market-driven mechanism to mitigate emissions from the largest carbon-intensive sectors (Baumann et al., 2002; Albino et al., 2009). In the power sector, for instance, renewable energy – as one form of a green product – was primarily driven by stringent climate targets (IPCC, 2014), public incentives and increasing demands of environmentally-conscious consumers (Marques and Fuinhas, 2011; Masini and Menichetti, 2013). In other emissions-intensive industries such as the steel sector, however, progress towards cleaner production has been incremental over the past decades, relying on existing emissions reduction measures with minimal effect on reducing the carbon footprint of steelmaking (An et al., 2018). The introduction of breakthrough clean technologies with potential to radically reduce emissions from steelmaking, such as carbon capture, utilization and storage (CCUS) technologies and hydrogen direct reduction, has been hampered by a number of factors, notably their high costs (Vogl et al., 2018; Liang et al., 2019).

To address the cost barrier, a number of recent studies (e.g. Element Energy, 2018; Muslemanni et al., 2020) recommend the development of a market for premium lower-carbon, or 'green', steel products as a potential means of creating a revenue stream to support the implementation of breakthrough clean technologies. The term 'green steel' is here defined as steel 'manufactured using lower carbon routes, where greenness is a function of reduction in emissions during production, not of lesser amounts of material used or of carbon content in finished steel products' (Muslemanni et al., 2021). 'Green steel' remains a concept that, until recently, has rarely been discussed in the literature (Arens and Vogl, 2019; Sutherland, 2020; Muslemanni et al., 2021). Even less known is the consumer's behaviour towards and willingness to adopt greener steel in final products.

The automotive sector offers a potential market for green steel. The sector accounts for 12% of overall steel consumption worldwide, second only to the construction sector (Worldsteel, 2018). While the construction sector accounts for the majority of global steel use (51%) (Worldsteel, 2018), a case for green steel uptake by the sector is, at least in this study, dismissed for two main reasons. Firstly, the construction sector's supply chain is risk-averse, highly decentralized and intensely fragmented, making it exceptionally difficult to coordinate efforts between its many actors, especially as they also operate on very small profit margins. Secondly, steel is only one component in the final make-up of buildings, and consumers do not perceive greenness of buildings in terms of emission reductions during their construction but of energy usage throughout their lifetime (Sichali and Banda, 2017). Hence, this study investigates the opportunities and challenges of incorporating green steel into the automotive sector's value chain, as a first step towards its integration into other sectors.

While the automotive sector has made salient efforts to produce 'cleaner cars' over the past decades, these efforts have been predominantly focused on reducing emissions from the vehicles' in-use phase, or 'tailpipe' emissions (e.g. through enhanced fuel efficiency measures and/or shifting towards producing electric and hybrid vehicles). The literature has accordingly appraised consumer behaviour towards those measures/alternative products (e.g. Achtnicht, 2012; Hackbarth and Madlener, 2016; Hulshof and Mulder, 2020). However, there are arguments that focusing only on improving fuel

economy may not suffice to achieve meaningful emission reductions, since 1) from a lifecycle perspective, efforts may not reflect true environmental commitments, and 2) consumers may simply respond by driving more (West et al., 2017). Automakers' receptiveness towards procuring greener materials in their manufacturing operations, especially greener steel, is an area which is poorly explored. This paper aims to address that gap, by appraising the perception of market stakeholders towards introducing greener steel into production processes.

This study contributes to the general literature on environmental sustainability practices in auto manufacturing and advancing the business case to expedite the adoption of breakthrough technologies in the steel sector. Here, automakers, rather than end-users, are considered 'consumers' of green steel. The paper is structured as follows: Section 2 provides background to this research, including an overview of drivers of green consumerism and their relevance to green steel. Section 3 outlines the research methodology employed, while Section 4 presents key findings and discussions. Section 5 provides recommendations and concludes.

2. Theoretical background

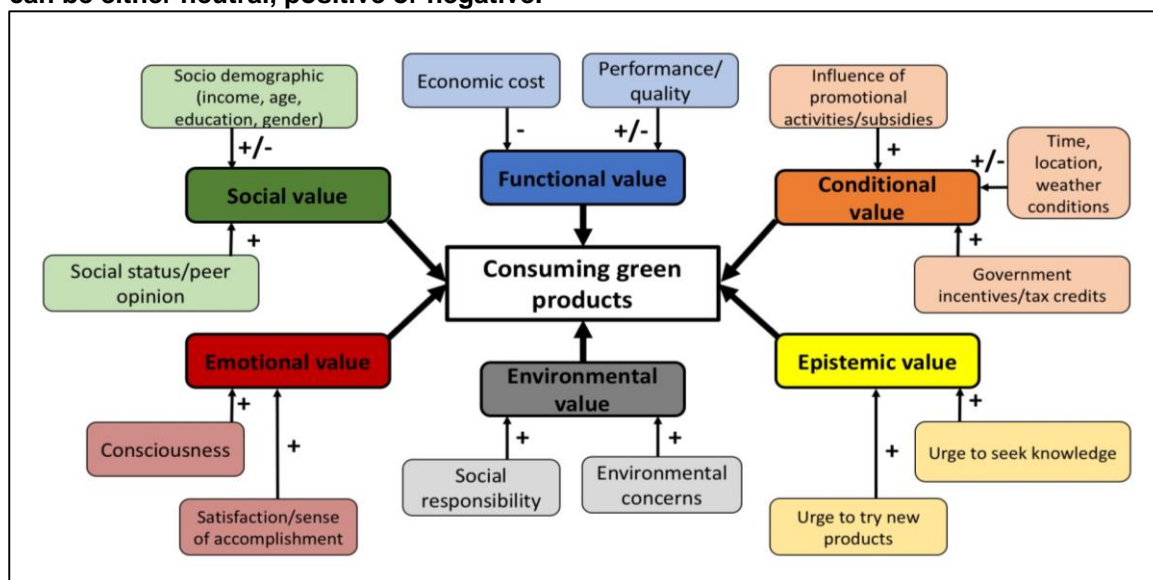
2.1. Drivers of green consumerism

Consumer attitudes are associated with knowledge of and personal experiences with the products they consume (e.g. Davidson et al., 1985; Chamorro et al., 2009; Garg, 2015). The desire to 'consume green' specifically has been reported to be a function of various aspects including: cultural factors (Anderson and Cunningham, 1972), personality and socio-demographic characteristics (Drozdenko et al., 2011), trust and credibility (CBI, 2011; Matthes and Wonneberger, 2014), and economic costs (Lynn and Oldenquist, 1986; Osterhus, 1997). A green consumer is here defined as 'a consumer who adopts environmentally-friendly behaviours and/or who purchases green products over the standard alternatives' (Boztepe, 2012). Green consumers are often internally-controlled, i.e. they believe that individuals, rather than governments, businesses, environmentalists and/or scientists alone, are responsible for environmental protection (Young et al., 2011).

A theory developed by Sheth et al. (1991) proposes several 'consumption values' to explain the drivers of green consumerism including 'why consumers choose to buy or not to buy (or use or not use) a specific product, and why consumers choose one product type over another' (Gonçalves et al., 2016). These values include: social value (Taormina and Chong, 2010; Suki, 2016), environmental value (Luo and Bhattacharya, 2006; Mobley et al., 2010; Biswas and Roy, 2015), epistemic value (Laroche et al., 2001; Ginsberg and Bloom, 2004), emotional value (Koller et al., 2011), functional value (Tsay, 2009), and conditional value (Laroche et al., 2001; Lin and Huang, 2012; Rahnama and Rajabpour, 2017). These drivers and consumption values are presented in Figure 1, where the relationship between the subcomponents of each value and the consumption of green products is highlighted: subcomponents can contribute positively (+) to the perceived value in question, negatively (-), or either (+/-).

While this model presents consumption values pertinent to individual consumers, there is evidence of commonalities in green purchasing behaviour at a corporate level, where it is linked to financial performance (equivalent to the functional value above) (Dubey et al., 2013; Yook et al., 2018) regulation and business environment (conditional value) (EITayeb and Zailani, 2010) and customer and shareholder pressure (social value) (Yen and Yen, 2012). Environmental values/concerns have often been reported as the main driver of green purchasing behaviour (Olson, 2013; Wei et al., 2017). However, there are claims that the potential environmental benefits arising from green products alone are not enough to attract consumers, whether individuals (e.g. Kley et al., 2012) or corporations (e.g. EITayeb and Zailani, 2010), as they normally carry higher price tags than do conventional alternatives (Deif, 2011; Olson, 2013; Ritter et al., 2015). This adverse effect may be further exacerbated by reduced size and/or performance of green products.

Figure 1: Conceptual model of consumption values and drivers of green consumerism.
 Notation '+' denotes a positive relationship, '-' a negative one, and '+/-' a relationships that can be either neutral, positive or negative.



Source: Figure drawn by the authors.

It is also widely acknowledged that the lack of consumer willingness to pay premiums for green products (in this case automakers paying a green steel premium) may in turn affect a manufacturer's (i.e. a steelmaker) sales (Yuhanis, 2004). This pressures manufacturers to more effectively communicate the benefits of green products to their customers, through ecolabelling or targeted marketing campaigns for instance (Murali et al., 2019). One way to reduce the high costs of green products or enhance the consumer's willingness to adopt them, Bhatia & Jain (2013) suggest, is for governments to enact environmental standards which trigger innovations that lower product costs and/or improve its value. The interplay between these consumption values collectively determines the willingness of automakers to adopt greener steel in production, as discussed next.

2.2. Corporate willingness to adopt green steel

Recent research provides ample evidence that consumers are willing to pay a relatively higher price for greener products (e.g. Roe et al., 2001; Moon et al., 2002; Bjørner et al., 2004; Shen, 2012). In parallel to this, green producers normally sell such products at higher prices compared to conventional 'brown' ones (Yuhanis, 2004). The difference between the market price of a conventional product and its greener, more expensive alternative is called a 'price premium'. Premia can both be expressed in percentage or dollar values, and are considered a direct proxy of the consumer's environmental consciousness (Chekima et al., 2016), or in the case of a corporate entity, its social responsibility commitments.

However, despite many studies stating the consumer's willingness to pay (WTP) a premium for greener products, the *actual* price that consumers are willing to pay remains debatable (Mandese, 1991; Ong et al., 2015). This is often attributed to differences in product categories, different market segmentations and consumer profiles, and most critically, the usage of conceptually different methods to elicit the willingness to pay for the products. There are also reported cautions of consumers overstating their willingness to pay a premium for environmentally-friendly products in order to engage in socially-desirable behaviour (Bjørner et al., 2004; Park, 2017).

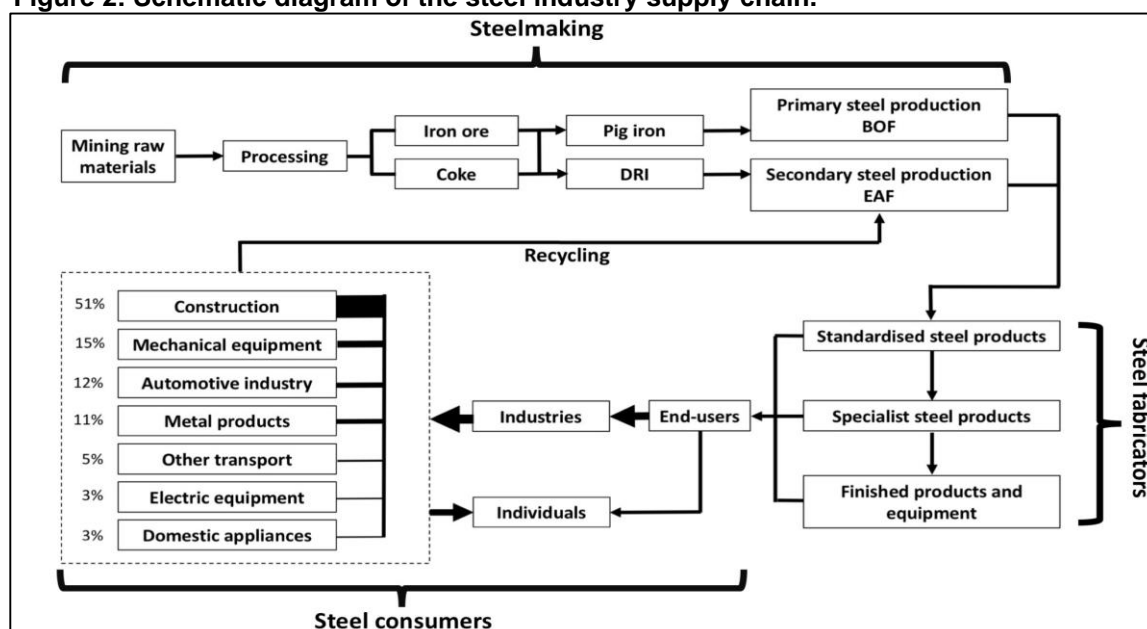
Studies investigating individuals' WTP have often been used in the literature as a tool to forecast adoption rates of innovative technologies or products at a corporate level (e.g. Asgari and Jin, 2019; Karytsas et al. 2019; Olum et al., 2020). For green steel, however, it may be difficult to elicit the consumer's WTP due to a number of factors, most notably that it is not straightforward to define who

the ‘consumers’ of steel are as opposed to consumers of other finished green products who are normally individual end-users (Figure 2).

In fact, eliciting the user’s WTP for green steel would be especially challenging since

- 1) a variety of industries with different supply chain structures rely on steel as a major input material, such as construction, automotive, and mechanical equipment industries;
- 2) there is a relative disconnect between different supply chain actors (Shekari et al., 2011) where it would also be practically difficult to elicit WTP of each actor for the greenness of the final steel produced;
- 3) proportions of steel in the final products’ makeup vary across industries (e.g. roof toppings vs cars) and across different products within the same industry (e.g. different automakers producing different car models), which in turn will affect the level of premium consumers would be willing to pay for the greener steel in those products; and 4) large-scale WTP studies which can generate meaningful results would be excessively costly for researchers. Due to these reasons, we focus on directly appraising the willingness to adopt green steel at intermediate stages along the supply chain, where large points of steel use – ones which are predominantly or exclusively concerned with sourcing or ‘consuming’ steel – exist (i.e. automakers) (Figure 2).

Figure 2: Schematic diagram of the steel industry supply chain.



Source: Adapted from Muslemani et al. (2021).

Percentages of global steel consumption by sector are representative of steel usage in 2018, as reported by Worldsteel (2018).

3. Results & discussion

To examine the willingness of automakers to adopt green steel, semi-structured interviews were conducted with key industry stakeholders. The target population was key industry stakeholders from international, regional and country-specific automaker associations and vehicle manufacturing groups/automakers. Participants were recruited from the top 20 automakers by production volume (based on 2017 figures), who are currently operating within the top 20 countries by production, as ranked by the International Organization of Motor Vehicle Manufacturers (see appendix for more details on research design and methodology).

3.1. Green thinking in the automotive sector

While environmental efforts in the automotive sector have been traditionally focused on reducing emissions, these have almost exclusively targeted the vehicle's tailpipe emissions, with lesser regard for emissions from their manufacturing phase. These efforts have materialized in a shift towards producing hybrid and electric vehicles, and/or using lightweight materials in manufacturing (lighter vehicles lead to improved fuel economy and hence lesser emissions produced). However, this trend has been recently changing, partly driven by calls for transparency over green claims in the sector, where electric vehicles (EVs) have, arguably misleadingly, been labelled as 'zero-emissions vehicles' (ZEVs) (Malaquias et al., 2019). On this, interviewee 13 noted:

'Purely from a tailpipe standpoint, EVs are zero-emissions, but the fact is that it takes energy to get it to that tailpipe, or even to the vehicle itself if nothing necessarily comes out of the tailpipe. We are now looking aggressively as a company at reducing the CO₂ footprint from our supply chain as a whole – from the extraction of materials through to our suppliers and our own manufacturing facilities, to the development and use of our products'.

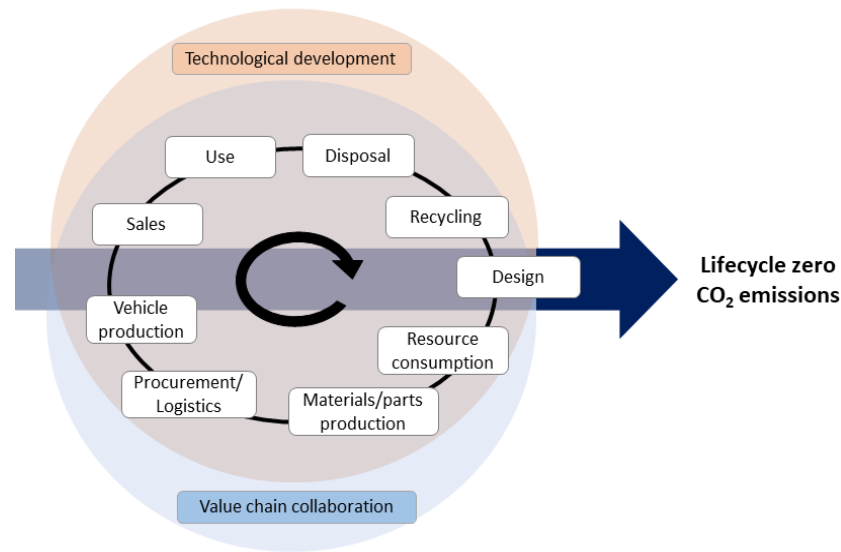
Indeed, the majority of study respondents (17 out of 22) maintained that there has been a recent sector-wide focus on greenness of upstream operations, driven by new overarching environmental sustainability trends in the sector, including reporting on supply chain carbon footprint and exploration of scope 3 emissions (Stoycheva et al., 2018). The sector has further moved towards embracing a more holistic lifecycle thinking in emissions accounting, evidenced in openly-accessible company strategy reports. Respondents attributed this move to internal factors, such as employee pressures and voluntary management commitments to enhancing corporate image, but also to increasing external pressure from the wider financial market and stakeholders, including key clients, NGOs, and society as a whole.

As part of these sustainability strategies, and inspired by recent Paris Agreement climate targets, the automotive sector is currently looking at procuring greener material in manufacturing, shifting from a tank-to-wheel approach to a well-to-wheel one when accounting for their emissions (the sector aims to achieve carbon neutrality by 2050, with a 37.5% interim emissions reduction target by 2030, compared to 2021 levels) (Automotive News Europe, 2020). Evidence of this is apparent in recent company-led initiatives, some of which are in place purely for internal regulatory purposes. These include: General Motors Company's (GM) goal of using 50% sustainable material in their fleet from 2030,¹ Volvo Group's participation in the WWF Climate Savers program to tackle emissions from its supply chain (Volvo Construction Equipment, n.d.) and Toyota's 2050 Environmental Challenge. Toyota's strategy involves six 'challenges', the second of which aims to eliminate CO₂ emissions from the entire vehicle lifecycle (Toyota Motor Corporation, n.d). These commitments are further reflected in increased discussions with material suppliers – steelmakers in particular – over introducing greener material into the sector's value chain (Figure 3). As an example, BMW recently invested in electricity-based green steel production by US steelmaking start-up Boston Metals (Automotive World, 2021). On this new trend, interviewee 15 asserted:

'I think our suppliers have a general understanding that they have to do something to keep up with where material industries are going, as sustainability will be a major part of the equation moving forward. Timing, however, is an important factor. The steel industry is traditionally not the quickest mover because of how capital-intensive the business is. We are in discussions with steel suppliers to try to reach a baseline, and as we have committed to the Paris Agreement, green steel in particular will be a major part of our requirements'.

¹ Based on personal communications with GM officials, with target to be made public in GM's forthcoming 2020 annual sustainability report.

Figure 3: Value chain in the automotive sector.



Source: Figure drawn by the authors.

Complementing this, from a steel supplier's perspective, the urge to report on lifecycle emissions performance is equally driven by customer demand for greener material as it has been by public mandates. Interviewee 12, chairman of a global equipment construction association, noted that:

'We supply equipment to both public projects and private companies. If we consider some of the major construction suppliers in the world, Skanska for instance, we see that they have around 20-30 big clients – or 'key accounts' – with strong sustainability agendas and who are requiring emissions disclosure from us. One such big account is the recently-contracted High Speed 2 (HS2) rail project in the UK, which is the largest environmental project in the country. This, in addition to public procurement, is the driving force in this sustainability transition, and a similar trend may well be seen with OEMs'.

These commitments, however promising, raise a few important questions.

First, what defines sustainability in the context of material production, supply, and use by an automaker? Interviewee 12 argued that while being 'sustainable' may be defined as using recycled or bio-materials, from a CO₂ standpoint, this may not always be as sustainable as using certain virgin materials or relying on other material families or if, for example, another supplier industry (e.g. aluminium) achieves a breakthrough in emissions reduction. Interviewee 17 further maintained that it would be much easier for automakers if material industries established international standards to allow comparison between different suppliers – something that is currently being sought out by the ResponsibleSteel and Aluminium Stewardship Initiatives (ResponsibleSteel, 2019; ASI, n.d.). The main reason for this, interviewee 17 believed, is that it is difficult to account for a vehicle's Scope 3 emissions:

'As an automaker, we have the tools to internally calculate Scope 1 and Scope 2 emissions, but we struggle to accurately measure Scope 3 emissions: we are in the process of being able to calculate emissions from logistic transportations. Scope 1 and Scope 2 emissions constitute around 95% of our production's carbon footprint, so we can argue that we are able to report on around 97% of our overall lifecycle emissions, but, by setting international standards, metal suppliers would help us to account for the remaining 3%'.



In addressing this, ArcelorMittal, the world's largest steelmaker, recently announced plans to offer green steel certificates under a carbon offset scheme, XCarb, which would help customers – including automakers – to mitigate their Scope 3 emissions (ArcelorMittal, 2021).

Second, automaker efforts to account for lifecycle emissions have all, at least until now, been voluntary. For passenger vehicles, regulation on CO₂ performance has largely targeted tailpipe emissions only: for example, as of 2021, a fleet-wide average emission target of 95 grams of CO₂/km will be applicable for new cars in the EU (European Commission, 2020a²). A number of interviewees referred to this CO₂ performance threshold as a 'universal currency' which dictates, at the board level, what new technologies and materials may or may not be incorporated into new production lines. The significance of this target – whether for producing vehicles with green steel or with any other greener materials – is remarkable: if the target went beyond tailpipe emissions to include overall supply chain emissions, there would be an instant demand for greener material in manufacturing.

For instance, the carbon abatement costs of energy-saving technologies in passenger vehicles can range from €250–280/tCO₂ for diesel and hybrid cars, up to €500/tCO₂ for electric vehicles (Fan et al., 2017; Peng et al., 2018). For energy-efficiency measures in steelmaking, carbon abatement costs can average about €20–25/tCO₂ based on the choice of measures (Fan et al., 2016), making it around 10 to 25 times cheaper to abate overall emissions from steelmaking than from vehicles. Admittedly, amending a tailpipe-only CO₂ performance target may be highly difficult (and potentially infeasible) due to political reasons, as

1) automakers and their representative associations may lobby against making fundamental changes to long-established supply chains, and

2) it may counterproductively (and counterintuitively) undermine the sector's climate commitments in the public view, as it may be seen as a means of escaping stringent regulations. Yet, this does speak to the need and opportunity for steelmakers and automakers to cooperate towards meeting their individual climate targets through innovative solutions (Rootzén et al., 2016), or bridging emissions regulation between the steel industry (e.g. emissions trading scheme = cheap) and the vehicle industry (fleet target values = immensely expensive).

Third, as far as the sector's demand for steel in general is concerned, an important distinction must be made between different types of vehicles and their corresponding markets, and whether, and how, their manufacturers may price them if made with green steel. This is because steel may account for different proportions of total material input in different vehicle types (e.g. light-duty vs heavy-duty), within which it may or may not be possible to substitute steel with other materials (e.g. aluminium and plastic composites). The next section discusses this discrepancy with a focus on different vehicle types based both on size (relevance: amount of steel used) and powertrain options (relevance: how emissions are allocated throughout the vehicle's lifetime). At a higher level, these are categorized according to size (i.e. light vs heavy), under which vehicles of different powertrain are discussed (i.e. diesel/petrol, hybrid and electric).

3.2. Green steel in different vehicle types

Historically, steel has been and continues to be the most used material in vehicle manufacturing, accounting for around 60% of materials in a typical passenger vehicle (Statista, 2020). However, due to new manufacturing innovations, an increasingly diverse set of customer demands, and environmental restrictions, this trend is changing. For instance, passenger vehicle manufacturers are shifting towards using lightweight material (e.g. aluminium and composites) which offer similar performance to steel in terms of durability and resistance, except at a weight reduction and hence a fuel efficiency advantage (Tisza and Czinege, 2018). In heavy-duty vehicles (e.g. trucks, buses and coaches), demand for steel has been increasing as larger trucks are being produced on average³, which is also reflected by the larger steel bars produced by steel manufacturers to cater to the commercial truck market (Santos et

² Automakers would be penalized €95 per each gram exceeded above the average 95g/km limit on each of its passenger cars registered during that year (European Commission, 2020a).

³ Between 1990 and 2019, the average weight of a pickup truck has increased by 1,142 pounds (i.e. 518 kg) (Neil, 2020).



al., 2017). These trends are even more pronounced when considering the amount of steel used within passenger cars and heavy-duty vehicles: there is around 900kg of steel per car (Worldsteel, 2020), while a typical mid-size truck may contain around 2.8 tonnes of steel (combination of hot- and cold-rolled) and a similar amount of iron, totalling around 5.5 tonnes of iron and steel.⁴ The implications of these trends on potential demand for green steel in the sector are here presented.

3.2.1. Light-duty vehicles (LDVs)

3.2.1.1. Internal-combustion engine vehicles

In discussing the likelihood of green steel serving a role in decarbonizing passenger cars over their lifetime, interviewees had mixed responses. On the one hand, a number of respondents noted that original equipment manufacturers (OEMs) and consumers alike would be keen to do the ‘right thing’ and move towards greener cars where possible; however, the majority of interviewees stated a myriad of reasons why this is unlikely to materialize.

First, incorporating green steel into LDVs will certainly come at a price: an increase in production costs, and a likely subsequent increase in the cars’ retail prices. As argued by a number of respondents, manufacturers of mid-size, internal combustion engine (ICE) passenger vehicles operate at such low profit margins that they are highly unlikely to pass these costs down to their customers, and are just as unlikely to absorb those costs themselves. Similarly, customers may not be willing, or able, to pay premiums for cars made with green steel. This is due to two reasons: 1) the additional cost required – which may average around €200 per car (Muslemanni et al., 2021) – may be proportionally too high a premium to pay for the majority of medium-income customers, and 2) customers are generally more concerned with fuel economy – whether for cost savings or environmental benefits, or both – than with how a car is made (Kushwaha and Sharma, 2016; Chowdhury et al., 2016). From a marketing perspective, this will create a particular obstacle for a ‘green steel car’ manufacturer; the reason why, interviewee 11 asserted, is that:

‘No matter how green someone wants to be in terms of the products they buy, it all comes down to a purchasing decision and it is all based on cost. We have seen this with our own hybrid vehicles: as we get closer to cost parity, people will buy them. I do not think there is a big market for people wanting to pay more for a green badge on the vehicle. As we see electric vehicles with only between 1-5% adoption rates, I do not really see consumers wanting to pay more for a car because we make it out of green steel’.

Second, and perhaps more tangible, steel is competing with other materials that can substitute its application altogether in LDVs. Many automakers are procuring aluminium or high-performance polymer composites for their higher stiffness-to-weight ratios which allows for additional payload: most famously, in 2014, Ford replaced steel with aluminium in many components of its F150 fleet, pushing its competitors to follow suit (Weber, 2018), which almost doubled the global demand for aluminium in the sector (Djukanovic, 2016). The steel industry, in particular ArcelorMittal, has since moved towards producing advanced high-strength steels (AHSS) which offer significant weight savings compared to traditional steels of comparable strength. This, a number of interviewees argued, leads to a healthy competition amongst the ‘big three’ materials in the sector – steel, aluminium and composites/polymers – where they would increasingly push one another from a green standpoint, especially with regard to carbon footprint. ArcelorMittal and SSAB have also recently moved towards producing greener steels (SSAB, 2019; ArcelorMittal, 2020). With this in mind, a case for green steel adoption in passenger cars can be made if AHSS is produced with green processes, which would offer both a light *and* green advantage and would thus likely mitigate the competition.

Third, the possibility of using green steel in the manufacture of passenger vehicles can be highly region- and context-dependent. For example, in Sweden, local automakers (e.g. Volvo Group) are able to collaborate with the HYBRIT hydrogen-based steelmaking project (Pei et al., 2020) where the latter

⁴ Estimates based on personal communications with a truck manufacturer.

may potentially not need automakers to pay premiums for their greener steel, depending on market conditions and future subsidies. In such a case, green steel may be more competitive than aluminium, both in terms of greenness and cost. On the contrary, in North America, and particularly in Canada, the opposite is true. Canadian aluminium boasts the lowest carbon footprint in the world, averaging around 2 tonnes of CO₂ emissions per tonne of primary aluminium produced (Aluminium Association of Canada, 2018). This is in vast contrast to the world average of 12–17 tCO₂ from one tonne of aluminium production (Saevardsdottir et al., 2020). Moreover, Canadian automakers, bound by the new USMCA rules, are required to source 70% of their steel and aluminium materials from the NAFTA region (i.e. Canada, USA and Mexico) (Office of the United States Trade Representative, 2020), leaving little to no space for exported steel (green or otherwise) to compete. Unless North American steelmakers switch to greener and low-cost steel production, aluminium may remain the metal of choice in North American passenger cars (interviewee 11⁵).

3.2.1.2. Energy-efficient vehicles

Energy-efficient passenger vehicles include hybrid electric (HEVs), plug-in hybrid electric (PHEVs) and fully-electric vehicles (EVs). While emissions from HEVs and PHEVs vary and depend on how many times they are charged and are running on electricity (i.e. the more often, the greener, assuming use of clean electricity), EVs emit no direct emissions (considering only tailpipe emissions). The relevance of this to green steel is that 1) lifetime emissions of these vehicles lie mostly or exclusively within their manufacturing phase and in the generation of electricity used during manufacture, and 2) green steel cars may need similar heavy subsidies and regulatory mandates which are seeing energy-efficient vehicles penetrate the automotive market. In focus on EVs, interviewee 7 argued:

'EVs have not been produced for the purpose of increasing profit – they're supported by credit. The market for EVs has been driven by two things: regulatory compliance and self-mandates. Due to regulation, many automakers are obliged to sell a certain number of 'zero-emission' electric vehicles to offset emissions from their ICE vehicles'.

Interviewee 3 further echoed this by stating that:

'Regulation at the moment is the only business case for electric cars'.

Indeed, these regulations have been so restricting that automakers have forged new partnerships with other automakers to help meet CO₂ performance targets (i.e. 95 gCO₂/km) at a fleet-wide level. For instance, Fiat Chrysler Automobiles (FCA) and Honda have partnered with Tesla to create a so-called 'open-pool' of vehicles which allows FCA and Honda to offset CO₂ emissions from their cars against Tesla's EVs (Allan, 2020). In this pooling, Tesla sells its emissions credits – called 'supercredits' – for hundreds of millions of euros to other automakers struggling to meet their CO₂ targets, who in turn avoid fines in the order of billions. Ford has similarly pooled its fleet with Volvo's to avoid such fines (Bolduc, 2020).

While these partnerships speak to the strategic importance and implications of a CO₂ performance target within the automotive sector, they also emphasize the very high CO₂ avoidance costs in the sector: a single car is fined in the order of €10,000 if the automaker fails to meet its target. It follows that if the CO₂ performance target included lifecycle emissions, these costs could be more cost-effectively offset by purchasing greener components. Additionally, current efforts are not necessarily helping achieve carbon neutrality, since, by producing more so-called zero-emission vehicles, upstream emissions can simply be shifted to regions which do not conform to the same standards and regulations (e.g. China). From a holistic lifecycle perspective, therefore, an EV is not serving its CO₂ mitigation purpose:

'The CO₂ performance regulation of today is not driving any development in what type of materials we use in our vehicles, except for moving towards lighter materials to compensate for new components that add weight' (interviewee 10).

⁵ NAFTA countries accounted for 18% of global vehicle production by volume in 2019 (OICA, 2019).

An argument for incorporating green steel into energy-efficient vehicles, especially EVs, may be made assuming that EV buyers are environmentally-conscious and likely enjoy higher incomes, and may thus be willing to pay a premium for a greener car. However, evidence shows that despite the high subsidies and tax credits which have been channelled towards the EV market (Wang et al., 2019), the uptake rate of EVs globally remains considerably low: 5% of market share in Germany, 3.5% in Canada, and 1% in the US (IEA, 2020). There are also concerns that EV subsidies may not be as cost- and environmentally-effective as stringent across-the-board standards on fuel economy (Harvey, 2020). Moreover, producing EVs with green steel may not find marketing merit with consumers who may be confused by the allocation of a greener badge to a car that has already been labelled as 'zero-emissions'.

A number of respondents argued that, due to higher profit margins on their products, manufacturers of luxury vehicles or light- and heavy-duty trucks may be more willing to incorporate green steel into their vehicles, and potentially pass costs down the chain and/or absorb part of the costs themselves (ZumMallen, 2017). However, there is growing evidence that luxury-vehicle manufacturers are more likely to substitute steel with aluminium and lightweight carbon composites, as their vehicles do not need the load-bearing advantage that steels offer. A recent market trend report by McKinsey and Co. (2020) notes that luxury vehicle manufacturers are willing to pay around 8-10 EUR per kg saved (on total weight of the vehicle) for the advantages associated with lightweighting (e.g. up to 35% in weight savings) (p. 15). Aluminium and polymer composites (especially plastics) are thus expected to grow significantly as materials in luxury vehicles (Research and Markets, 2019), except where high-strength steels are needed (e.g. in transmission and steering). Interviewee 21 echoed these projections:

'Luxury vehicles are completely moving to higher composites, or even lighter-weight materials which are stronger. They would be completely out of steel in the next 10-15 years. So, the case for green steel is one to be made mainly in trucks. Steel mills today are making modifications to their manufacturing to accommodate truck requirements as they already see a decline for requirements from the car industry'.

Based on the arguments made above, green steel use in trucks, and in heavy-duty vehicles more broadly, is discussed next.

3.2.2. Heavy-duty vehicles (HDVs)

A number of interviewees recognized that it is just as challenging to meet CO₂ requirements in heavy-duty vehicles as it is in passenger cars, despite the discrepancies that exist in how emissions are regulated in their corresponding markets. For example, until 2019, there had been no equivalent regulations on emissions performance for heavy-duty vehicles in the EU as there were for passenger cars. As of August 2019, a new EU fleet-wide regulation requires large truck manufacturers to meet emissions reduction targets of 15% starting in 2025 and 30% in 2030, compared to average fleet emission levels in 2019/2020 (European Commission, 2020b⁶). Similar to the passenger car industry, these targets can be met by producing zero- and low-emission vehicles (ZLEV) for which a crediting system applies; and as the car industry, these targets involve tailpipe emissions only.

For HDVs, the industry's focus has been on reducing fuel consumption. Fuel consumption accounts for a third of a truck's operational costs (Sen et al., 2017), so fuel economy is one of the main factors which influences a customer's decision to purchase one (Sallee et al., 2016), and in turn, is a major competition area for truck manufacturers. In this, the move towards decarbonizing the HDV industry has largely focused on electrification – by producing both battery-electric and fuel-cell electric trucks (Lee and Thomas, 2017; Johnson and Joshi, 2018). The industry also aims to switch to light(er), strong materials; yet the increasing demand for high load-bearing capacities means that steel will remain the main component in trucks in the future. Acknowledging this, a number of respondents noted that using green steel will be key to decarbonizing heavy-duty vehicles, if a holistic lifecycle approach to emissions accounting were adopted.

Unlike for passenger cars, while cast aluminium can replace cast iron in some truck components, it cannot replace steel in others due to safety reasons. Even if possible, from a full lifecycle emissions

⁶ The new EU regulation covers large trucks, which account for 65-70% of all emissions from heavy-duty vehicles (EC, 2020).

standpoint, replacing primary steel with primary aluminium in HDVs may not serve an environmental purpose. Palazzo and Geyer (2019) show that this substitution leads to significant initial GHG emission increases before reductions are realized (i.e. due to light-weighting savings throughout the vehicle's in-use phase). The implications of this may be further exacerbated as 1) accounting for lifecycle emissions of materials in HDVs is not straightforward, considering the amounts of recycled material which are normally used in their manufacturing⁷, and 2) the fact that the increased use of recycled aluminium may not necessarily displace primary aluminium and steel production (Geyer et al., 2015), in which case overall GHG emissions reductions are never achieved. Steel from HDVs is also being increasingly recycled, however not necessarily for its green virtues. Interviewees from truck manufacturing companies explained that there is an established circular thinking when it comes to end-of-life steel-made components, simply driven by their weight and economic value:

'We don't have an end-of-life vehicles directive to trucks like we do for cars, meaning that we don't have a producer responsibility as to what type of materials we are allowed to use. But, because trucks are so valuable, people will take them and scrap them. There is at least 10,000 euros in a truck in terms of its metal content, and even more if different components are re-used' (interviewee 1).

This is supported by an existing and well-functioning second-hand market for used components, including green ones (European Automobile Manufacturers Association, 2020). Despite this, an increasing demand for heavier-duty trucks means that primary steel will still be needed as an input, and that this steel needs to be *green*, interviewees 10, 12 and 20 asserted. These views, nonetheless, show that there is an obvious mismatch between industry ambitions and consumer needs:

'I would say that there is close to no demand from our customers when it comes to how, or what types of material are used in producing our trucks. Still, there is an exception and that is in electric trucks which we have recently started to sell. I can say that there is some concern and requests for certain materials, especially for cobalt batteries, but before electric trucks there was close to no interest in this type of issues. It is an area of low priority for customers when it comes to choosing between different manufacturers and different trucks, unless there are incentives or direct benefits to them' (interviewee 10).

Indeed, a case for using green steel in manufacturing electric HDVs is a strong one. With an existing demand for primary steel and the fact that emissions are shifting towards the manufacturing phase in electric ones (especially in the production of batteries), electric HDVs are prime candidates for the uptake of green steel, at least in the first instance, especially if the manufacture of electric trucks were subsidized: an example of a heavily-subsidized initiative is that of Volvo Lights in Southern California (Shahan, 2020). To see this through, however, a few areas would first need to be considered.

First, circular economy thinking in the industry should account for the greenness of input materials. This can be achieved through a revision of the EU End-of-Life Vehicle (ELV) Directive (2000/53/EC) (European Commission, 2000) in line with the EU Green Deal, to add resource efficiency and minimal climate impacts to the set of requirements of materials used in and recycled from vehicles, effectively creating a case for 'green steel vehicles'. Second, this can be more easily adapted and implemented if there is an end-user demand for green products. At present, demand for greener material in the automotive sector has been coming from OEMs rather than end-consumers themselves. Similar to consumers of clean energy (Craig, 2016), eco-certified wood (Anderson and Hansen, 2004) and green buildings (Fuerst and McAllister, 2011), if automobile consumers were made aware of the energy and carbon footprint of their (heavy-duty) vehicles through marketing initiatives, they may become more inclined to change purchasing behaviours, and in turn companies their production strategies. Third, and perhaps most effective according to interviewee 10, both steelmakers and automakers can set

⁷ According to interviewee 20, around 90% of aluminium and iron in trucks is recycled material.



emissions targets as part of the Science Based Target initiative (SBTi): a few steelmakers including SSAB and Vale have already set science-based targets, accompanied by recently-joined automakers including Volkswagen AG, Volvo Car Group, Renault, Mercedes-Benz AG and Peugeot (SBTi, 2020).

4. Conclusion

This research has provided a comprehensive analysis of the possibility of integrating green steel into the automotive sector, with focus on different vehicular types in terms of size and powertrain options. However, it did not come without limitations. We aimed to provide a holistic overview of the demand for green steel in the sector by engaging with stakeholders from different regions and organizations. However, with limited access to industry stakeholders, the list of interviewed participants was by no means inclusive of all major automakers and associations in the world, especially as it did not include participants from one of the major production and consumption regions of automobiles – Southeast Asia. The adopted research methodology also does not guarantee a lack of subjectivity, as automakers may tend to speak in their own interests and their inputs may not be reflective of the industry's stance as a whole on the topic.

This paper shows that there is a new sector-wide shift towards achieving greener upstream operations and material sourcing in the automotive sector, however this is yet to be mandated through regulation. Existing initiatives have been driven by customer pressures and/or social corporate responsibility commitments instead of emission performance standards and financial returns, at least until such initiatives become subsidized or a substantial customer demand for green steel cars exists. Due to their ease of measurability, 'green' in this paper has been defined in terms of GHG emissions exclusively, notwithstanding the importance of other important environmental and social factors which are key to the sustainability of steelmaking. The case for incorporating green steels into luxury vehicles has been dismissed in this study as their manufacturers are moving towards consuming high-strength light-weight materials which can substitute the use of steel in light-duty vehicles, while electric light-duty vehicles are not considered an area for green steel uptake, at least at present, as the financial incentives targeted at them are yet to see them penetrate the market as a product.

The study shows that manufacturers of electric heavy-duty vehicles are most likely to be the first adopters of green steel use, until green steel is established as a mainstream and competitive product on the market. A case for green advanced higher-strength steels (AHSS) can also be made in light-duty passenger vehicles, which may mitigate competition from lightweight alternative materials in terms of cost and greenness (depending on source and utilization zones), and simultaneously enhance AHSS's competitiveness as an input material in auto manufacturing.

This work builds on a wide sustainability-related literature in the automotive sector and highlights areas in need of urgent action if the sector as a whole were to fulfil its emissions reduction aspirations. In particular, the authors recommend that existing CO₂ performance regulations in the sector are re-evaluated and amended to account for full lifecycle emissions, which would not only create an instant demand for greener material in vehicles, but also achieve corporate emission reductions and enhance the transparency of environment-friendly claims at significantly lower costs. Simultaneously, automakers can engage in educational green marketing strategies to inform customers of the embedded carbon footprint of purchased vehicles. They can further include green material, and especially green steel, adoption in manufacturing as part of company CSR strategies. In this, it is key that national and cross-border automaker associations oversee a transparent standardization process to ensure the credibility of an automaker's green claim.

This paper calls for further areas of research exploration, including appraising and comparing the effectiveness of subsidy provision for alternative green technologies in the automotive sector (e.g. EVs) against setting emission regulation standards on material usage and on fuel economy for ICE vehicles. There is also a need to investigate the influence of green steel adoption in auto manufacturing on steel supply by existing and newly-developed steel mills, and to explore the impacts of substituting aluminium with green AHSSs on lifecycle emissions of vehicles. This is especially timely as the aluminium industry is also moving towards producing greener products, creating what is anticipated to be a game-changing race between green steel and green aluminium in automobiles.



5. Appendix

5.1. Research design

To examine the willingness of automakers to consume green steel, semi-structured interviews were conducted with key industry stakeholders. A semi-structured interview approach is widely used as a data collection tool which guarantees responses to certain key aspects which the researcher(s) wishes to cover, but also provides participants a degree of freedom to introduce other ideas relevant to the main objective of the study (Connell, 2011; Suh et al., 2012). This approach allows for a flexible and creative in-depth discussion (Guest et al., 2013; Bryman, 2016) and is regarded as one of the most convenient and effective methods of collecting meaningful primary qualitative data (Kvale & Brinkmann, 2009).

The main methods of conducting semi-structured interviews are through face-to-face conversations, email, video conferencing or telephone (Denzin & Lincoln, 2012). However, limited by COVID-19 travel restrictions throughout the second half of 2020 and the international nature and limited availability of participants, all interviews were held online using video conferencing software (Teams, Zoom or Skype), by email or telephone. Interviews were held between June and October 2020, were between 1–2hrs in length, and, subject to an explicit consent from the participants, were audiotaped and later transcribed verbatim. Interviewees were informed of the objective of the study by email prior to holding the interview and were offered the option of anonymizing their inputs.

The main themes which the interviews covered were: 1) stakeholder perception regarding the role that green steel can play in meeting an automaker's climate targets, 2) demand for and viability of introducing green steel to the automotive sector, including challenges and opportunities, and 3) impacts on competitiveness with traditional steel and other substitutable materials. The list of interview questions is provided as supplementary material. Based on the interviewee's field of specialization within the sector, specific additional questions were tailored to enhance the value and quality of data collected.

5.2. Sample selection

The target population was key industry stakeholders from international, regional and country-specific automaker associations and vehicle manufacturing groups/automakers. Participants were recruited from the top 20 automakers by production volume (based on 2017 figures), who are currently operating within the top 20 countries by production, as ranked by the International Organization of Motor Vehicle Manufacturers (OICA, 2017; 2019) (lists provided in supplementary material). As automakers selected by production volume were not all-inclusive of luxury vehicle producers, further automakers were selected from an online luxury-vehicle database, Car Logos (n.d.), to complement the initial set of identified automakers.

Following a purposive sampling technique (Yin, 2011), the focus was on recruiting experts within these organizations who have sufficient knowledge of green initiatives, policy landscape and emission reduction advancements within the sector. This non-random technique guaranteed the selection of information-rich cases in a non-costly manner (Patton, 2014), and helped investigate a new area of research where there is a lack of observational evidence and which can guarantee conclusive results (Etikan et al., 2016). Experts included CSR and sustainability managers, manufacturing specialists, executive directors and presidents/chairpersons. Experts were initially identified from their respective organizational websites, public forums and LinkedIn company pages, and/or due to their participation in relevant industry conferences and workshops over the past 5 years and authorship of sustainability-related company reports. Where it was not possible to directly identify experts within a company, the researcher contacted the communications team and/or general contact lines of the association/company in question, either by phone or email, to be referred internally to relevant individuals with the desired expertise. To avoid bias, stakeholders were chosen from companies who may or may not be already implementing green initiatives or have emission reduction strategies in place.

A total of 247 invitations were sent overall, and at this stage, several stakeholders declined to participate, quoting one of the following reasons:

- Lack of knowledge/focus on product design and technology;
- Participation considered a conflict of interest as green steel adoption may impact competition and thus could not be discussed due to commercial/legal reasons;
- Some automakers and suppliers only view green steel use as a competitive advantage, and are thus not discussing the topic as an industry;
- Lack of interest of steel suppliers who exist within the automaker's area of operation in producing green steel; and/or
- Capacity restrictions on participating in external interviews as a company.

At this stage, 17 stakeholders opted to participate in an interview. During their interviews, they were further asked for personal referrals to other potential collaborators in a snowballing approach (Merriam & Tisdell, 2015). This method secured further 5 interviews, bringing the total to 22 interviews. Table 1 outlines the details of final participants; all responses were anonymized, except where indicated.

Table 1. Study interviewees

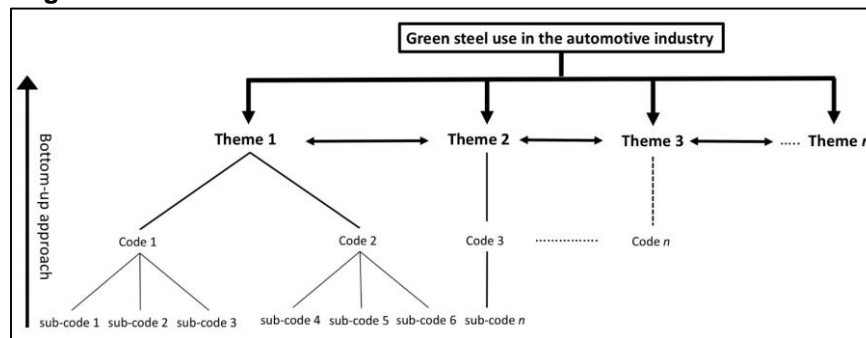
ID	Position*	Organization	Country/region
1	President	Global Automakers of Canada (GAC)	Canada
2	Executive Manager	NAAMSA/ Automotive Industry Export Council (AIEC)	South Africa/Global
3	Climate Protection Policy Manager	VDA	Germany
4	Sustainability Manager	Leading car producer	Germany/Global
5	Director	Automaker association	Italy
6	Sustainability Researcher	Toyota	Canada/Global
7	Executive Director	Association of Russian Automakers	Russia
8	CSR and Supply Chain Director	Automotive Industry Action Group	United States
9	Manager, Sustainability and Politics	Luxury car producer	Germany
10	Lars Martensson, Environment and Innovation	Volvo Trucks	Sweden
11	Head of External Affairs	Leading car producer	Canada
12	Chairman/Vice President Sustainability & Public Affairs	Swedish Equipment Construction Association (SACE)/ Volvo Construction Equipment	Sweden
13	Sustainable Materials Specialist	Leading car producer	USA
14	Sustainability Communications Manager	Leading car producer	USA
15	Engineering Group Manager	Leading car producer	USA
16	Senior Sustainability Manager	Heavy-duty vehicle producer	USA
17	Sustainability Manager	Heavy-duty vehicle producer	Sweden
18	Electrical Purchasing	Heavy-duty vehicle producer	Sweden
19	Sr. SAP Solution Consultant	Volvo	Sweden
20	Manager, Materials Technology	Volvo	Sweden
21	Synergy Purchasing Manager	Volvo	Sweden
22	Environmental Protection Manager	Luxury car producer	Germany

* Either interviewee identity and/or organization have been anonymized based on interviewee's preference.

5.3. Data collection and analysis

Following transcription, the data analysis software Nvivo (v.20) was used to dissect interview manuscripts into key 'units' in a thematic qualitative text analysis approach (Schulz, 2012): these units included paragraphs, sentences and/or phrases which relate to a separate theme (Stake, 1995). This involved an iterative process where inductive and deductive methods were combined to select common themes stemming from the interviews. Then, in a bottom-up approach, these units were assigned sub-codes and grouped under different higher-level codes (Braun and Clarke, 2006), which were in turn classified under one of the three highest-level themes identified in section 3.1, forming a three-tiered 'coding tree' (Figure 4).

Figure 4: Coding tree



Source: Figure drawn by the authors.

Throughout the coding process, codes were continuously refined, i.e. redefined or re-grouped together based on linkages with other codes, with the aim of narrowing down broader codes into more focused concepts. This was undertaken while ensuring relationships between different codes were kept intact and following a three-step framework inspired by Miles and Huberman (1994) which involves: data condensation, data display and drawing conclusions. Priority was allocated to different codes and their underlying sub-codes based on the frequency that overall interviewees voluntarily addressed them: this priority allocation is reflected in the structure of the narrative which ultimately emerged from the data analyzed, where the most pressing factors affecting green steel adoption in the sector are discussed first.

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