CATAPULT High Value Manufacturing

WMG THE UNIVERSITY OF WARWICK

Towards net-zero: Exploring the current state of low carbon supply chains in the Midlands

MIDLANDS ENGINE

Acknowledgements

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Contents

60-second summary

The United Kingdom is a global leader in the fight against climate change, having been the first major economy to enact legislation by setting an ambitious net-zero emissions target for 2050. To accomplish this goal, extensive, systematic change across all sectors, including industry, will be required. The Midlands, as the epicentre of industrial activity in the UK, has already begun this transformational journey. The low carbon sector, defined as the network of entities directly involved in the manufacturing and provision of low carbon technologies, is becoming increasingly important in the growth of the Midlands Engine pan-region. The UK's legal obligation to achieve net-zero emissions paves the way for significant improvements in manufacturing capabilities, due mainly to the region's robust research and development (R&D) activities and supportive stakeholders.

Despite its potential, the sector is constrained by a number of threats. A skills shortage, a lack of long-term relationships with upstream suppliers, and a lack of digital maturity and connectivity have long been associated with the British manufacturing industry. Other issues unique to the low carbon transition include a scarcity of critical materials for new technologies and products (particularly rare earth materials such as lithium or raw materials used in battery manufacturing such as cobalt and nickel), as well as concerns about legacy assets and the infrastructure used by various carbon-intensive industries.

Start-ups and emerging R&D companies deserve special consideration, as a lack of adequate funding to bridge the gap between R&D and mass commercialisation is a significant impediment to product development. Additionally, it appears as though they are having difficulty obtaining information about available funding and support mechanisms (e.g., sources of support for learning new skills, platform to build new partnerships). Additional obstacles include power imbalances in supplier relationship management (i.e., organisations and processes that prevent small- and medium-sized enterprises (SMEs) from participating), as well as weak demand signals, as the benefits of low carbon have not yet been communicated to the public. COVID-19 and Brexit have exacerbated these challenges, reducing earnings and increasing business complexity.

To address these issues, nine interventions have been identified: prioritisation and focus, customer centricity and public acceptance, infrastructure improvements, converting and fitting existing companies and infrastructure into low carbon supply chains, upgrading skills, collaboration, flexibility, recycling and focusing on circular economy principles, and redefining funding opportunities. Furthermore, demand-side policies aimed at influencing aggregate demand within the economy (for both carbon-intensive and low carbon goods and services) are proposed, as are supply-side policies aimed at increasing the supply of low carbon goods and services, encouraging collaboration among different sectors and stakeholders, and encouraging interoperability between different technologies.

Executive summary

This research focuses on the network of entities directly involved in the manufacturing and provision of low carbon technologies and services. This network is comprised of numerous businesses and organisations, most notably in the energy and mobility sectors. The report identified 95 entities as being part of the Midlands supply chain network, including small- and medium-sized enterprises (SMEs), large organisations, research-oriented institutes, governmental authorities and consortiums, and funding bodies. It is worth noting that this network is representative of the larger low carbon and environmental goods and services sector; however, the current mapping exercise is limited by the difficulty of capturing micro-companies without an online presence or with out-of-date websites.

R&D capabilities are the basics for significant value

The region possesses a strong R&D and innovation portfolio, with current R&D programmes focusing on areas such as battery developments, software for connected and autonomous vehicle-related (CAV) analysis, sustainable energy sources, and fuel cell technologies. These programmes are supported by universities and organisations that promote public-private collaboration. The Midlands has a strong reputation for engineering and manufacturing excellence; the transition to a low carbon economy will benefit from both inherited manufacturing and R&D capabilities.

Supply chain vulnerabilities: gaps in innovation, unclear regulation and more…

The low carbon regional development faces several vulnerabilities. Although support exists (both financial and technical), companies appear to have difficulty in accessing information about opportunities in the region. There appear to be gaps in the innovation process in terms of progressing from an R&D stage to the commercialisation stage. Another recurring topic in relation to vulnerabilities is the current regulation framework; lack of clarity in the use of hydrogen, long and complicated licences for electricity and gas supply, and grey areas for the use of sustainable CO2 are some vulnerabilities associated with public policy. In addition, local authorities seem to play a limited role in terms of convening power and aligning incentives.
Focusing on supply chain (SC) issues, there is widespread agreement that the Midlands (and the UK in general) cannot compete on cost with international SCs, and that competitive advantage should be sought through quality and/or technology measures. Additional concerns include the scarcity of Rare Earth Elements (REE) materials and their geographic distribution. Additionally, regional manufacturers continue to lag behind global competitors when it comes to digital maturity.

Brexit and COVID have aggravated the situation, but collaboration is reinforced

While the circular economy represents a significant opportunity for the low carbon economy by reusing materials, its application is still in its infancy. Batteries and electronics recycling options are limited, and waste management is inefficient, as the majority of waste is incinerated rather than used to generate energy. COVID-19 and Brexit have complicated the SC even further. Following the EU referendum, the UK reported negative results in a critical sector such as vehicle manufacturing, while businesses reported increased trade complexity and fewer opportunities. COVID-19 altered customer demand, necessitated employee restructuring and cash shortages, and impacted innovation pipelines. On the other hand, the pandemic has heightened the importance of collaboration and low carbon initiatives, while Brexit has resulted in a more regional approach to SC strategies.

Looking into the future, resilience can come from different sources

The industry should be able to adapt and change in response to future market demands. Infrastructure enhancements (e.g., designing efficient energy networks capable of meeting anticipated high demand, developing infrastructure to support testing and deployment of new technologies) should be prioritised in this regard. Understanding the consumer and fostering customer confidence in low carbon technologies and services are critical components of the transition to a decarbonised economy. Collaboration and adaptability are also required to build resilience; sharing best practices, designing interoperability among technologies, and embracing digitalisation can all help.

Upgrading skills and redefining current funding opportunities can also help. Because the region is home to a variety of organisations that can assist with both of these aspects, it is critical to improve and/or disseminate information about available mechanisms in an efficient manner. Furthermore, existing companies and infrastructure should be aligned with low carbon SCs. Finally, circular economy principles should be adopted to create new business opportunities and address material scarcity issues.

Different public policies can be used with the same objective: to promote decarbonisation

The report concludes with policy recommendations. In this regard, some examples include the establishment of a local development bank and the implementation of new financing opportunities (e.g., preferential rate loans, targeted grants for green investments). Appointing a single organisation as the main point of contact to promote information sharing and assist businesses in identifying the best assistance programmes that can fit their needs was a recurring theme. Updating legislation, re-evaluating the tax system (e.g., carbon border tariffs), enacting bans on high-intensity carbon products, and implementing carbon accounting policies can provide a framework for generating customer demand while reducing cash pressure in organisations, particularly during the R&D stages.

1. Introduction

1.1. Introduction and objectives

Since the global economic crisis in 2008, industrial supply chains (SCs) have undergone significant transformation. With technological innovation enabling greater autonomy and connectivity, as well as the UK's "net-zero" vision, businesses must reconsider how their SCs can enable greater sustainability, productivity, and prosperity. The need for change is becoming more apparent, and recent disruptions caused by the COVID-19 pandemic and Brexit – both of which pose challenges and opportunities for the Midlands region – necessitate an urgent re-evaluation of current practices. The time has come for the region to 'build back better' and establish resilient SCs for long-term growth. Building resilient low-carbon SCs is a critical component of success in this challenge, and it can contribute to the region's economic development through green recovery in the post-COVID era.

To support this vision, the Supply Chain Research Group (SCRG), WMG, University of Warwick has partnered with the Midlands Engine to identify potential interventions for building resilient low carbon SCs.

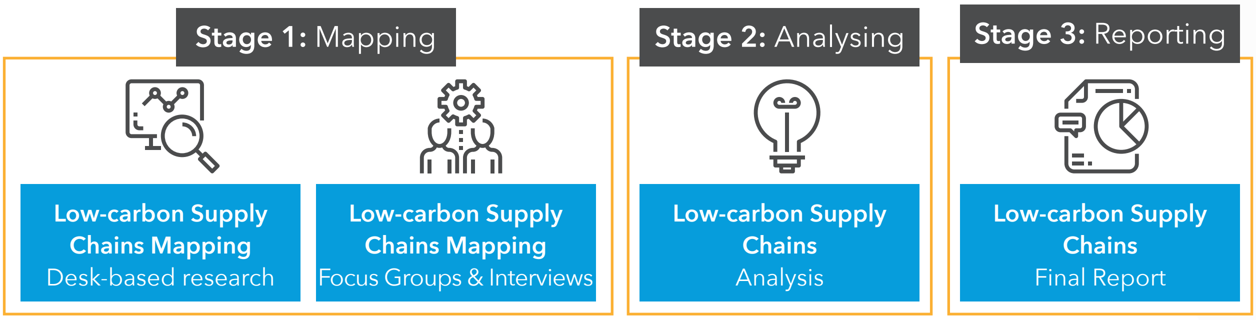
By focusing on the decarbonisation strategy and the legal commitment of the UK to reach net-zero emissions by 2050, and the decision of the Government to bring forward the ban on the sale of petrol and diesel cars to 2030 – decisions that generated a greater sense of urgency about achieving the Agenda's promise – this report will assess the sectoral capabilities of low carbon SCs in the Midlands region to provide a holistic overview of the sector and identify potential interventions for accelerating the efforts towards net-zero.

In this regard, the current study intends to:

- Understand and portray the specialisations and technological complementarities underlying low carbon SCs in the Midlands.
- Detect emerging clusters, understood as specialisation groups of firms/organisations linked by shared attributes such as markets or technologies.
- Reflect on how value is created by organisations working in low carbon SCs in the region.
- Identify the challenges organisations face in the low carbon sector in the region by collecting primary (interviews & focus groups) and secondary data (academic & grey literature).
- Explore the impact of COVID-19 and Brexit on the low carbon SCs.
- Investigate how the low carbon sector can build resilience.
- Provide a set of public policy measures that could promote the transition to a decarbonised economy and SCs.

1.2. Research methodology

The project followed a structured three-stage approach Mapping, Analysing and Reporting (Figure 1):



[1] Three-stage approach

Stage 1: Mapping

This stage involved mapping the low carbon SCs in the region and the relevant stakeholders (Companies, Local Enterprise Partnerships (LEPs), Educational Institutions and Local Authorities). For this purpose, two data collection methods were utilised:

- Desk-based research (secondary data): The data sources included both grey and academic literature, and the use of specialised databases.
- Semi-structured interviews (primary data): 10 interviews (each of approximately one hour's duration) and two focus groups (within a workshop) were conducted to build a broader understanding of low carbon SCs in the region.

Appendix 1 contains the details of the desk-based research and Appendix 2 comprises a summary of the participants in the interviews and workshops.

Stage 2: Analysing

The second stage followed a thematic analysis of the data gathered during the interviews and focus groups. This analysis was performed using the core themes derived from the objectives and pre-established during the preparation of the interview questionnaire (see Appendix 3). Based on the identification of common patterns and ideas across the different responses, the analysis focused on the identification of the current strengths of the region, vulnerabilities and disruptions, alternatives to building resilience, governance, and public policy options. The main themes were also contrasted with the available literature that can support the arguments and these are presented within the report.

Stage 3: Reporting

This stage included synthesising findings and writing up the findings of the research to summarise the main findings and recommendations for the low carbon sector.

2. Low carbon supply chain in the Midlands region

2.1. What falls within low carbon supply chains?

According to Das and Jharkharia [1], a low carbon SC can cover two angles: one regarding the operations involved in the regular supply chain management (SCM) (i.e., sourcing, production, planning, etc.) and the other considering the management of the embodied carbon (i.e. how many greenhouse emissions derived from the SC operations). To tighten the scope of this project, low carbon SCs are defined as the network of entities directly involved in the manufacturing and offering of low carbon products and services that can contribute to the reduction of the carbon footprint.

This definition will be presented using the Supply Chain Operations Reference Model (SCOR model), a framework that includes the main supply chain (SC) activities: plan, source, make, deliver, and return. For the purpose of this work, each part focuses on the following:

- **Plan:** aspects regarding what requirements, resources and plans are necessary in the energy and mobility business environment.
- **Source:** supply management and material provision to generate and produce energy and technology.
- **Make:** the generation of energy and manufacture of products
- **Deliver:** outbound of the products and offering of the services
- **Return:** activities involved in the product flow, from the customers to manufacturers or suppliers.

2.2. Current landscape of low carbon supply chains in the Midlands

2.2.1. Network analysis

Sustainability West Midlands and kMatrix have conducted research to measure the size of the low carbon sector in the region. According to their report, the low carbon and environmental goods and services are worth £26.6 bn in sales, include 10,500 businesses and employ around 195,000 people [2]. The study includes different sub-sectors such as wind, building technologies, alternative fuels, photovoltaics and others (see details in Appendix 4); however, it covers a bigger sample size compared to this research. While low carbon can be present in different sub-sectors, the purpose of this report is to analyse a sample of companies in the energy and mobility sectors engaged in the development and commercialisation of products and services in the region.

In total, 95 organisations were identified and selected for the current research. To analyse this network, organisations were first clustered into two categories – energy and mobility – based on the focus/application of their products/services. Considering that mobility and energy-related work has been prioritised equally and has been conducted interchangeably in some organisations, a third, combined 'Energy and Mobility' cluster was identified. The idea of energy and mobility, as two complementary areas to one another, will be further discussed in later sections. Next, categories were defined to describe these organisations' business activities.

As such, the following categories have been used in the research:

- **Technology** (includes companies that offer products/software services that aim to lower carbon emission levels)
- **Energy generation** (includes companies that generate energy from varied sources)
- **Distribution Network Operator** (DNO) (includes licensed companies that own and operate the wires and pipes that carry electricity and gas into homes and businesses)
- **Energy supplier** (includes companies that bill homes and businesses for the energy they use)
- **Aggregator or intermediary** (includes companies that offer market access and support to players in the energy sector)
- **Service and/or Operations and Maintenance** (O&M) provider (includes companies that develop/build/install/operate/maintain energy systems and power plants, and companies that offer services related to low carbon: shared mobility/private vehicles)
- **Vehicle manufacturer** (companies that manufacture low carbon vehicles in the UK)
- **R&D** (organisations that provide R&D support to accelerate the UK's decarbonisation)
- **Consortium** (includes governmental organisations and trade associations that have initiated projects related to low carbon transport)
- **Funding and support** (includes entities that fund and support low carbon projects)

Sub-clusters were also developed to describe in more detail the technologies/services these organisations provide, and the technology that energy generation companies employ in order to produce energy. In addition to the previously described series of data (clusters and sub-clusters), the industry types the organisations are part of were also added (for more information, please see Appendix 5).

2.2.2. The Midlands landscape

Figure 2 highlights the organisations included in the mapping exercise, based on the criteria defined in the methodology. The organisations located outside the Midlands region are included because they are actively involved in projects and/or are offering services in the Midlands. Similarly, Table 1 represents the organisations by application, organisation type and cluster, and Figure 3 illustrates the ranking of the nodes based on betweenness centrality[1]. Based on this analysis, 'Technology' is connected to significantly more nodes within the network than the rest of the nodes, demonstrating the region's focus on innovative technologies that are meant to help the energy as well as the transport sector to transition towards low carbon (e.g., additional energy sources, alternative fuels, vehicle technologies, carbon capture and storage, energy management technologies).

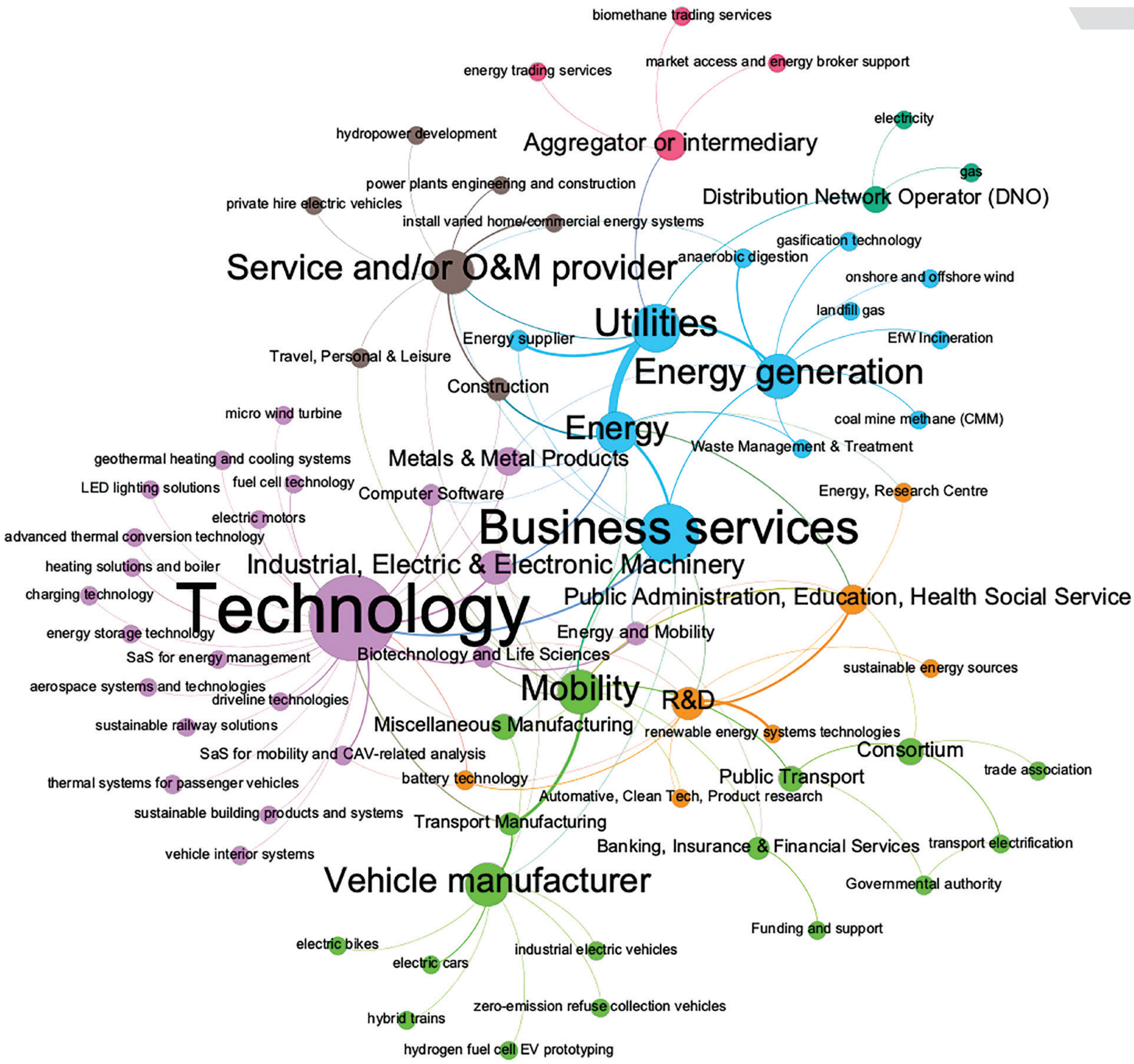
[1] Betweenness centrality (in the network diameter analysis) is an important measure of the node's influence within the whole network; this shows how often the node appears on the shortest path between any two randomly chosen nodes in a network.

Figure 2. Low carbon mapping in the Midlands

Table 1. Low carbon mapping exercise: organisations by application, organisation type and cluster

Application[2]	Organisation type	Cluster	No of organisations
Mobility	SME	Technology	7
		Service/O&M provider	1
		Vehicle manufacturer	2
	Large organisation	Technology	8
		Vehicle manufacturer	6
	Research-focused institute	R&D	3
	Governmental authority or consortium	Consortium	4
	Funding body	Funding and support	1
Energy and Mobility	SME	Technology	5
	Research-focused institute	R&D	3
	Funding body	Funding and support	1
Energy	SME	Technology	6
		Energy generation	4
		Service/O&M provider	6
	Large organisation	Technology	4
		Energy generation	10
		DNO	2
		Energy supplier	9
		Aggregator/intermediary	3
		Service/O&M provider	4
	Research-focused institute	R&D	6

[2] whether the goods/ services offered by organisation have an application in the mobility/energy industry



Transport/mobility is considered to be a significant contributor to emissions (up to a fifth of UK greenhouse gas emissions [3]), hence the increasing R&D in technologies applicable in the automotive sector. Companies of all sizes are actively looking into innovative ways of de-carbonising and electrifying mobility. **Furthermore, when it comes to specialisation, i.e. groups of firms/organisations linked by shared attributes such as markets or technologies, one might notice that, currently, driveline technologies, software for mobility and Connected and Autonomous Vehicles (CAVs) have become more popular.** Other themes that are explored at the present time are **fuel cell technology** and **battery technology**.

In addition, low carbon solutions and technologies have also been identified in the construction sector (purple nodes connected to technology in Figure 3). Technological advancements have allowed buildings and homes to become increasingly environmentally-friendly and 'intelligent'. This 'intelligence' is manifested through advanced control solutions built on data and algorithms that monitor consumption-related patterns (i.e., water and energy consumption), and built-in architectural solutions and technologies that can generate, capture, and/or distribute energy (i.e., solar panels, electric chargers, etc.). With the UK Government's plans to make it a legal requirement for new buildings to be built with charging points for electric vehicles, this will increase even further. This is also included as part of the Industrial Strategy Clean Growth Grand Challenge which aims to use new technology and modern construction practices to at least halve the energy usage of new buildings, both commercial and residential, by 2030 [4].

Reducing carbon can come in many forms. Being resource efficient and creating less waste by using less material or recycled material will inherently have carbon benefits, and these practices have been adopted by low carbon technology firms. In addition, especially in the automotive industry, **organisations are increasingly adopting a 'designing with the end-of-life recyclability in mind' approach**. A specific interest in this regard has been linked to serviceable, upgradable, and recyclable lithium batteries. As such, issues around materials, as an extension of energy and mobility-related initiatives, are equally important and being explored at the moment, but are still very much in their infancy.

The UK Government also calls for the transposition of waste management into sustainable material management, where resources are utilised for as long as possible to minimise waste. Energy from waste can be referred to as a circular economy practice because it encourages a continual use of resources. Circular economy, in contrast to the linear approach summarised as 'take, produce, consume, and dispose', keeps materials as long as possible in the loop. As such, generating energy from waste addresses two significant global challenges simultaneously.

The current SC mapping exercise does not include sectors such as the chemical sector, the rear earth magnet sector (magnets are used in almost every electric machine up to 60% of its value [5]) and other sectors associated with the production of low carbon technologies. A comprehensive analysis of the end-to-end SC that is focused on one specific technology solution rather than an overview of the low carbon sector should be conducted to map all different tiers and sectors associated with low carbon. Another limitation of the mapping exercise is that the data collection relied on data gathered online; hence, companies that do not have an online presence were not identified (specifically micro and small companies). However, the database itself comprises a representative sample of organisations involved in low carbon SCs (with a focus on the energy and transport industry) and, as such, has unveiled insights for the current state of the sector.

2.3. Value creation

Through the data collection process, the following themes emerged in relation to value creation in the region:

- general, regional focus on innovation and R&D
- access to research-intensive universities and institutions
- presence of organisations that promote and support business growth
- regional engineering and manufacturing excellence
- presence of organisations looking into upskilling and reskilling local workforces
- presence of organisations that provide testing facilities for new technologies

The Midlands has a proud history of innovation. From the invention of the steam engine and the first practical bicycle in the 18th century, and the first automated traffic lights in the early 20th century, to the UK's first multi-city testbed for 5G technology and advances in low carbon technology, the Midlands has made its mark at an international level [6]. The SC mapping exercise presented earlier confirmed that the region currently has a flourishing innovation ecosystem. Innovation stakeholders include large firms such as Jaguar Land Rover – that recently announced its new strategy to go all-electric by 2025 [7] – but also SMEs that claim to make the world's first serviceable, upgradable and recyclable lithium batteries [8] or are even offering a feedstock flexible conversion technology that classifies for end of waste and has the capacity to affectively accomplish negative carbon from multiple feedstocks [9]. In addition, there are companies exploring and offering software solutions for mobility-related analysis, such as driverless vehicle platforms and connected vehicles.

Universities around the UK have increasingly become involved in economic development and have progressively increased their engagement in the definition and implementation of national strategies [10]. These institutions are not only skill providers but also drivers of change, strengthening linkages between their education and research missions and the economic and social objectives of their region [11]. In addition, the role of universities in innovation ecosystems is evident and has a clear impact on the specialisations present in their region [12]. Institutions in the Midlands are focusing on the research areas illustrated in Table 2. These institutions also have a strategic impact on the geographical location they operate in, through partnership and development opportunities with varied stakeholders. In addition, the region has a good set of commercial R&D centres that support R&D programmes and the enhancement of capabilities [13]. By fostering the link between education, research and innovation, the region will benefit in the long term.

"We have a business program supporting approximately 150 business in cleantech and low carbon technology. […] we've supported about 1000 SMEs across the whole Midlands. So, we work with small businesses and we also work with major companies in the UK such as JLR, but also big energy companies like NG. And I think that is about 40 companies we're working with in terms of energy R&D." (Interviewee 1)

The Midlands also hosts organisations that offer a platform for developing new collaborations and bringing capabilities together. A particular example is the UK's Catapult network where each Catapult is unique and associated with a particular technology domain. Based in Birmingham and Derby, Energy Systems Catapult supports companies to develop products and services in relation to energy systems, covering electricity, heat and combustible gases. High Value Manufacturing Catapult (a network of another seven centres), with its head office outside of Birmingham, embraces all forms of manufacture and leads the UK's green manufacturing revolution. Furthermore, launched in 2018, UK Research and Innovation (UKRI), a non-departmental public body, brings together nine councils that shape and deliver both sectoral and domain-specific support. Through UKRI, organisations can benefit from research council grants, quality-related block grants from Research England, or grants and wider support for innovative technologies from Innovate UK.

Transitioning into low carbon SCs requires a deeper understanding of what it takes to build a decarbonised economy, including a workforce with new skills. A particular area of concern is how might existing manufacturers/suppliers fit into low carbon SCs and how these firms might alter their products/services to produce and deliver cleaner sources of power. In this regard, some organisations during the study pointed out that they are actively seeking to upskill and reskill local workforces and are taking on apprentices. Higher education institutions are also exploring ways to increase students' learning outcomes while addressing changing labour market needs. A growing number of universities now offer an optional industrial placement year that allows students to acquire skills for the real world.

To transition to a low carbon economy with appropriate SCs, innovative but commercially proven and market-ready technologies have to be introduced in the market, so testing facilities are necessary in order to build the case around the benefits of these technologies. Testing is a vital step in enhancing public confidence in a company's products, and the Midlands is well positioned with testing capabilities in the following areas:

- testing technologies such as sustainable fuels, hydrogen, and carbon capture
- testing services for CAV-related systems and testing infrastructure for vehicles
- real-world testing environment for whole energy systems (electricity, gas, heating, and transportation)
- real-world testing environment for customer behaviour and interaction with new technologies (evaluating how people interact with products before entering the market)

Table 2. Universities in the region and their specialisations[3]

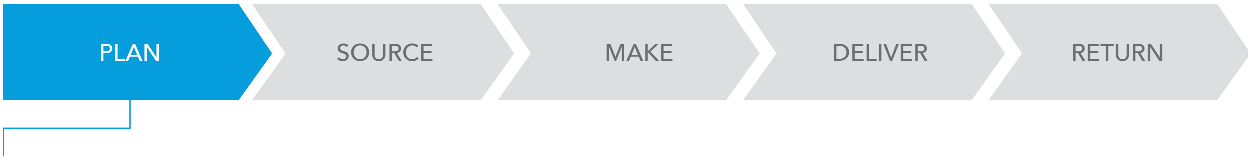
Universities	Key University Facilities/Projects	Specialisations
Aston University	European Bioenergy Research Institute (EBRI) Power Electronics, Machines and Power System Group	bioenergy solutions, products and services from a wide range of waste material, theoretical and practical aspects of power electronics and their impact on electrical power networks
Birmingham City University	Powertrain Test and Development	hybrid-engine research, exploration of cleaner burning fuels and bio-fuels
Coventry University	Institute for Future Transport and Cities Centre for Advanced Low Carbon Propulsion Systems (C-ALPS)	safe and sustainable transport solutions, low carbon transport propulsion solutions
Cranfield University	Hydrogen Research Network	hydrogen research
Keele University	Institute for Sustainable Futures	low-carbon energy research, hydrogen heating research, blending hydrogen into natural gas
Loughborough University	Energy Global Challenge	renewable energy generation, energy storage systems for the management of heat and electricity, alternative fuel, bio-fuels, fuel cells, electric engines
University of Birmingham	Birmingham Energy Institute	energy systems, bio-fuels, bio waste to energy, supercritical fluids and hydrogen fuel cell development
University of Leicester	Space Park Leicester	integrating space observation data into environmental analysis of automated routing and transport modes
University of Nottingham	Low Carbon Energy and Resources Technologies Research Group Institute for Aerospace Technology	carbon capture technologies, cleaner coal technologies, biomass thermochemical conversion, smart materials, aerospace electrification, aerospace materials and structures
University of Warwick	WMG	battery research, cell engineering, power electronics, machines, drives, intelligent vehicles, sustainable materials and manufacturing, digital technologies
University of Wolverhampton	Built Environment Climate Change Innovations	innovative climate change solutions within the built environment

[3] Based on available information on universities' websites

3. Exploring SC vulnerabilities and disruptions

3.1. SC Vulnerabilities

The low carbon industry offers an opportunity to help the UK meet its 2050 carbon targets. However, the industry faces a variety of challenges that could inhibit its growth. This section identifies vulnerabilities using the Supply Chain Operations Reference Model (SCOR model). Figure 4 depicts six planning-related vulnerabilities.



- Industry overview: one-dimensional industrial base and lack of trust in SMEs
- Complicated funding and support
- Failures within innovation process
- Legacy: what should be done with current assets?
- Disjunctive policies in energy, heat and transport
- Weak local governance

Figure 4. Plan-related vulnerabilities

First, **the industrial base appears to be one-dimensional**, built around the automotive and aerospace sectors, so any shock to these two sectors can cause significant damage to the majority of manufacturers in the region. The product and service portfolios available in the region have a limited customer base, limiting further exploitation and making the region more vulnerable to economic downturns. Despite the fact that the automotive sector is a key player in the low-carbon transition, overseas competitors with technological advantages such as Tesla, Volkswagen, or SAIC (EV leaders) and unexpected disruptions such as COVID-19 pose challenges to regional SC operations. Furthermore, a challenge for the region is the current ownership model of the largest manufacturers, which is dominated by foreign ownership [14].

Secondly, there appear to be **challenges regarding public and private funding**. Even though the national government provides various mechanisms to assist businesses in the low-carbon sector (including investment opportunities), companies appear to be overwhelmed by the abundance of alternatives and have difficulty accessing clear information, leaving them unsure about how to choose the best alternative for their business case. They often abandon or delay their plans due to the complexity of the process [15]. At the same time, private funding appears to be unsuitable for the manufacturing industry. Respondents emphasised the limitations imposed by banks in this regard, creating barriers to securing the necessary capital for projects. In the case of SMEs, lack of knowledge is exacerbated by SMEs' unwillingness to give equity to investors in order to access these opportunities (contrary to a model that works well in European countries such as Germany), reducing the option to obtain cash for their developments.

> *"Typically, High Street lending from the banks doesn't really provide the funding that SMEs need for making steps in two directions at once: improving their manufacturing capability and shifting their product and service portfolios"* (Interviewee 8)

The third point is about the **failures that occur during the innovation process**. Following the R&D stage, where follow-up funding is required to reach mass commercialisation, there appears to be a lack of attention and support [16] [13]. This is related to the fact that most organisations focus on developing new products and not on developing a business model and SCs that would guarantee a route to the market.

> *"People forget what the actual definition of innovation is (…) The formula for innovation is actually invention plus commercialisation. And I think the innovation in the net-zero agenda is predominantly just invention in a way"* (Interviewee 6)

Another important aspect, looking into the future, is the **plan around current assets and capital infrastructure**. Decarbonising homes is going to be challenging considering that 23.4 million homes in the UK were built before 1980 [17] and a high number of households are associated with fuel poverty [18]. Internal combustion engine (ICE) vehicles will also be operating for the foreseeable future [19] considering their long lifespan and an immediate replacement or second use will not be possible at once. Consequently, consideration of this intermediate stage is necessary for the transition and looking at different options to decarbonise these assets whilst they are still in use is part of it.

Energy, transportation and heat are now inextricably linked due to the sharing of common resources (electricity as a way to heat homes, cars using power networks, potential use of hydrogen in heat and/or vehicles), but **regulation is still preventing their collaborative development**. In addition, it appears that different sectors are now working together to decarbonise the economy, as evidenced by the quote below. For example, the growing emphasis on electric vehicles and related infrastructure demonstrates the energy sector's role in decarbonising mobility.

"The energy grid is now planning around some of the strategic direction for decarbonising transport in a way it wasn't before" (Interviewee 7)

Finally, local authorities could play a pivotal role in terms of **convening power** (community leadership, project initiation, local initiatives), aligning incentives (jobs, fuel poverty, CO2 reduction targets, waste reduction), **de-risking** (planning, support, waste contracts, own estate contracts), and **providing finance** (revenue accounts, grants, prudential borrowing, credit enhancements) [20]. However, it seems that, compared to their European counterparts, UK local authorities lack the powers to legislate in low carbon areas and their resources are limited due to years of austerity. The West Midlands Combined Authority has proved to be a good example of leading low carbon initiatives with programmes such as the Energy Innovation Zones, but work in this regard still depends on funding availability. Considering that solutions in local areas should be different than those in urban areas, expertise from local authorities could play a key role in the low carbon path, but this is yet to be realised.

The formula for innovation is actually invention plus commercialisation

- Cost pressure
- Power imbalance in the supplier relationship management
- Lack of critical raw materials and components

Figure 5. Source-related vulnerabilities

In the sourcing process, three main vulnerabilities have been identified, as presented in Figure 5. The first one, cost, limits the expansion of local SCs as they cannot compete in terms of price unless demonstrating value through quality or technology. Consequently, high-value parts are generally imported due to a better cost opportunity. In some cases, such as micro-mobility products, low cost is an essential attribute, thus it might be a key factor in some tendering processes (i.e., electric scooter programmes around the Midlands favouring international suppliers).

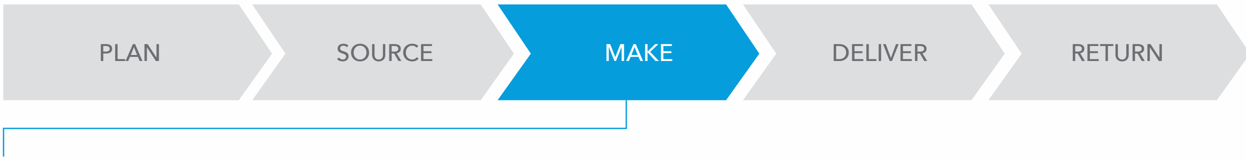
"The main issue is cost, and even if we do establish the supply chain, the ability to undercut that supply chain by going abroad is very likely" (Interviewee 4)

Large companies do not always collaborate with smaller organisations and public procurement processes tend to go for bulk quantities, hindering the participation of SMEs due to the impossibility of delivering the required quantities. In general, there appears to be a lack of trust in the SMEs.

"There are few companies that are big enough to tender for supplying the NHS with every ambulance across the country [...] tenders should be made regionally to allow competition between different players, including small companies [...] the traditional decision-making process in an organisation like the NHS needs to change" (Interviewee 3)

The last vulnerability is related to the **lack of critical raw materials and components**. There is a limited supply of critical components for EVs and electric machines [21] and most REE are currently supplied from China (China controls 90% of REE materials [5]). This represents a threat to the development of more specialised manufacturing sectors. One of the experts argued that supply issues often appear in tier 2 or 3 of the SC, affecting the smallest companies. In addition, lack of sustainable biomass [22] and food waste pose difficulties for the energy sector (i.e., energy generation from waste). In this case, it was mentioned that waste is locked in long incineration contracts or is being exported.

"These rare materials (for lithium-ion batteries) are subject to certain vulnerability of the supply chain. If there is any absence or if there is any country that is a leader in producing those materials, they can dictate the price; there is quite a bit of price volatility and this will of course affect the supply chain" (Interviewee 5)



- Industry related: relying on one cluster-technology; neither flexible nor dynamic
- Operations related: digital maturity and scale up
- Policy related: difficulty with current processes or lack of policies

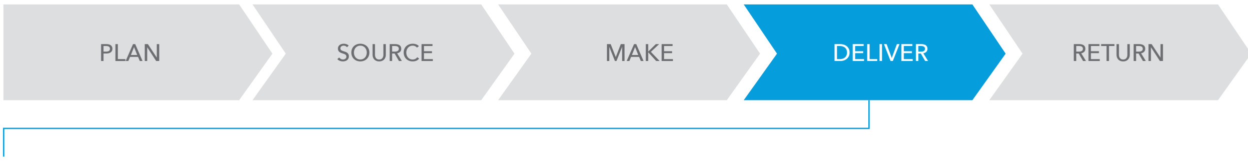
Figure 6. Make-related vulnerabilities

In the third stage of the SCOR model, three further vulnerabilities have been identified (see Figure 6). First, the industry seems to rely **on a one-cluster technology as most manufacturing capabilities target vehicle production**. Furthermore, the automotive sector is not changing at the required pace to understand what the trends are, lagging behind overseas competitors in the production of new cells, power systems, motors, and innovations.

The second set of vulnerabilities is focused on the businesses; there appears to be a **low level of digital maturity among businesses in the Midlands**, as well as the UK in general. The Midlands Manufacturing Resilience Commission has already presented their findings on how far British manufacturers have progressed in terms of automation and new technology adoption [14], and the low carbon sector is not exempt from this trend. Also, there are issues around the interoperability of different technologies. If automation and integrated systems are part of an end-to-end SC integration, this would allow technologies to fit into a more interconnected/wider system. SMEs face additional challenges in relation to the scale up of their operations and difficulties in accessing the engineering skills required to support the sector.

"Interoperability is a key challenge; while manufacturers produce a product, which has to be good on its own, now this must fit in a wider system which is more interconnected (…) it must be compatible with other technologies" (Interviewee 5)

Finally, the third set of vulnerabilities are related to public policies. At the moment, there is a **lack of clarity around the implementation of hydrogen;** it is still not settled whether it will be used in transport, heating or both, and it is unclear what infrastructure requirements are necessary to implement hydrogen. In addition, difficulties to scale up and high costs associated with hydrogen production inhibit its growth potential [21]. All these difficulties and uncertainties around hydrogen limit private investments in this technology. Another concern is related to **the generation of energy from waste**, which is restricted to sites where it can be combined with carbon capture and storage technologies.

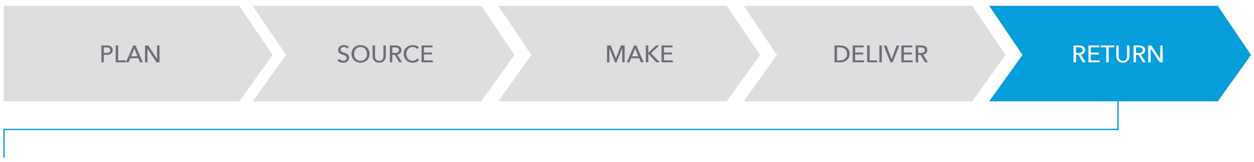


- Consumer concerns: safety, acceptance and simple recognition of low carbo products
- New consumption patterns

Figure 7. Deliver-related vulnerabilities

In the penultimate stage of the SCOR model (presented in Figure 7), two main vulnerabilities have been identified. There appear to be **consumer concerns regarding the safety of new technologies**. The safety of automated driving systems is a particular area of concern and is still under investigation before obtaining full approval for mass use. Furthermore, the public acceptance of low carbon technologies is low, due to several reasons: the benefits of low carbon technologies are not disseminated in a clear manner and most products that are currently on the market cost more than conventional technologies.

Another vulnerability that affects mainly the energy sector, lies in the **new demand patterns**. Global warming has generated extreme temperatures at both extremes, and new ways of living (such as working-from-home arrangements) could change the demand peaks of energy. Demand patterns in relation to mobility have been affected by the pandemic (people who work from home do not commute) as well as the popularity of EVs; electrification of fleets adds complexity to the required capacity for the electric grid. In the long run, the latter might affect the requirements for infrastructure and energy capacity and could have significant implications in the ways of delivering energy to houses and businesses.



- Circular economy options still in the initial stage

Figure 8. Return-related vulnerabilities

Finally, in relation to the last stage of the SCOR model (Figure 8), the main vulnerability is the **current state of the circular economy**. Despite being a promising solution in closing the loop on waste materials, its development is still at the initial stage. Considering the risks regarding the supply of critical components/materials, circular practices would allow businesses to keep production running.

3.2. SC disruptions

The COVID-19 pandemic and Brexit have meant exposure to a new range of challenges. Comparing and contrasting these two events it may safely be said that COVID-19 has brought about a year of tremendous change and it occurred suddenly, whereas Brexit was a slow burn. First, COVID-19 and the lessons learned from this event will be discussed, then the focus will be tilted towards Brexit and its impacts.

3.2.1. COVID-19

In the data analysis phase, the negative impacts brought about by COVID-19 have been clustered into two major groups: planning-related challenges and barriers to innovation. In general, it is identified that planning is affected by:

- **change in customer behaviour and demand**
- **restrictions regarding face-to-face interactions**
- **employee restructuring**
- **travel restrictions**
- **lack of cash**

Planning has been an issue during the pandemic due to the constantly changing environment and changes in demand patterns. In some circumstances, as highlighted during an interview, *"customers got cold feet although the purchase order has been already sent out"*. It is not only difficult to manage these types of circumstances on a personal level with a client, but a company's financial profile can also be tremendously impacted (especially when a project is worth millions of pounds), further causing employee restructuring and other difficulties among personnel, that are causing additional challenges in relation to planning. Activities carried out at testing facilities were also disrupted by restrictions regarding face-to-face interactions.

Changes in demand patterns are also evident by the decreasing national vehicle production output. As pointed out by one respondent, during the pandemic car output fell by 29.3% in 2020, to its lowest level since 1984 (see Figure 9 for more details). Since most of Midlands' top ten manufacturing powerhouses are made up of machinery and vehicle manufacturers [23] and the motor vehicle industry clearly plays a crucial role in the region, the pandemic has further impacted associated SCs that play a significant role in the low carbon sector.

UK Vehicle Production

Output hit by Covid, but EU-UK deal reduces uncertainty over outlook

- Car output fell -29.3% to its lowest level since 1984 in 2020
- £11.3bn lost value from C19
- Exports still 80% of output
- CV volumes down -15.5%
- Engine output -27% to 1.84mn
- 2021 startedoff weakly, as expected, with cars -27.3%
- Feb data out on Friday

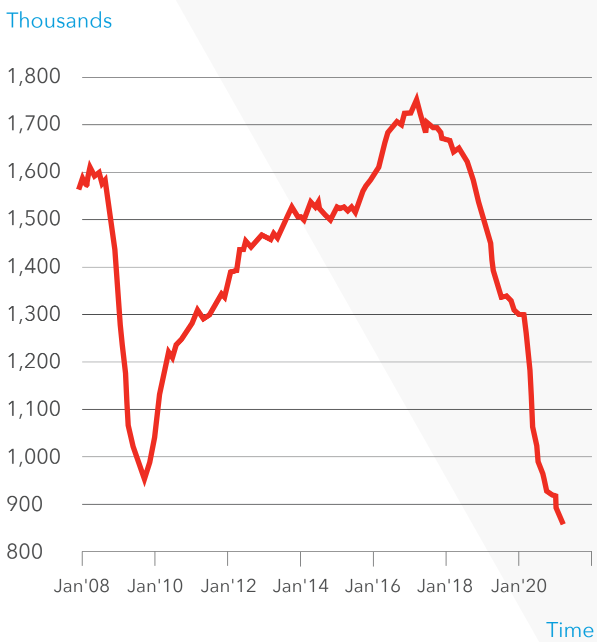


Figure 9. UK vehicle production hit by COVID-19 (SMMT, 2021)

Lost opportunities also emerged due to travel restrictions. For instance, one interviewee pointed out that consultancy services were disrupted, and delivering services abroad was impossible due to the self-isolation rules in place. It was considered unreasonable to expect staff to self-isolate twice (both at entrance to the destination country and on returning home), hence delivering a project in such circumstances can impact the quality of the outputs. Furthermore, some projects were affected and delayed due to restrictions regarding face-to-face interactions, and reduced cash flow also had a negative impact.

Companies, however, mentioned that the Government's furlough scheme allowed them to mitigate some of the negative effects of the pandemic. Downsizing running costs and effective use of resources were also mentioned as effective measures. This indicated that the responses to COVID-19-related challenges were somehow reactive. However, for small, more flexible companies, it seems that it was relatively easy to adjust to the new realities:

"We do not have a formal risk management process, but we have a risk register for all of the projects[…] A flexible approach is required, especially in a time like this, so maybe it worked in our favour not having a formal one […]" (Interviewee 6)

For some organisations, however, COVID-19 was a ***"challenge and an opportunity in a way"*** and as such, the pandemic has pushed the agendas of different organisations into the sustainability field, increasing the amount of research in this matter. In addition, planning has been prioritised during this challenging time (i.e., in relation to day-to-day operations and future direction of organisations to secure new business).

"We used the time to build the pipeline of the projects and do a lot of planning. We also developed new projects with private businesses in the EU that would secure future revenue sources" (Interviewee 6)

This year has been particularly difficult for SMEs and R&D-focused organisations that previously relied on face-to-face networking events to find new partners, investors, and customers. Working from home appears to have slowed down innovation, which is at the heart of the low carbon industry. As opposed to finding new customers and identifying new business opportunities, more attention has been given to nurturing existing relationships which were forged between the private and public sectors.

"For an R&D company creativity is very important. Being creative and supporting creativity is difficult during COVID-19" (Interviewee 3)

"During these times a key area we focused on was customer service and how we can ensure that there is a close relationship between us and our existing customers" (Interviewee 2)

Partnering with a reputable academic institution and research centres can generate new and strong links, particularly at a time when 'finding the perfect match' – in terms of suppliers and partners – might seem more difficult than ever. A particular example in this regard is the Ventilator Challenge UK – a consortium of significant UK industrial, technology and engineering businesses from across the aerospace, automotive and medical sectors led by High Value Manufacturing Catapult, a group of manufacturing research centres in the UK – that has come together to produce medical ventilators for the NHS.

- **COVID-19 has placed a new emphasis on relationships. While relationships mattered before the pandemic, now they are everything.**
- **Academic institutions and research centres can play the role of connectors and facilitate stronger, more diversified SCs.**

3.2.2. Brexit

Similarly to the section discussing COVID-19, the negative impacts brought about by Brexit have been clustered into different groups: **increased complexity, fewer opportunities for businesses and organisations, and uncertainty regarding the future.**

Brexit has led to a significant increase in bureaucracy, due to the additional new checks now required. In fact, for small businesses, the piles of paperwork and new trading regulations have caused significant challenges. Lead times have also increased. Training was mentioned as a mitigating measure, pointing out that organisations that had prepared in advance for Brexit have managed it better.

"The cost of shipping has become disproportionate to the value of the goods. The lead times and delays in getting goods have gone through the roof and the paperwork in the legislation and the import duties are insane now […] training has been the key […] we attended free Government webinars […] As well as working alongside our external accountants to keep up to date and what we need to do along the way" (Interviewee 3)

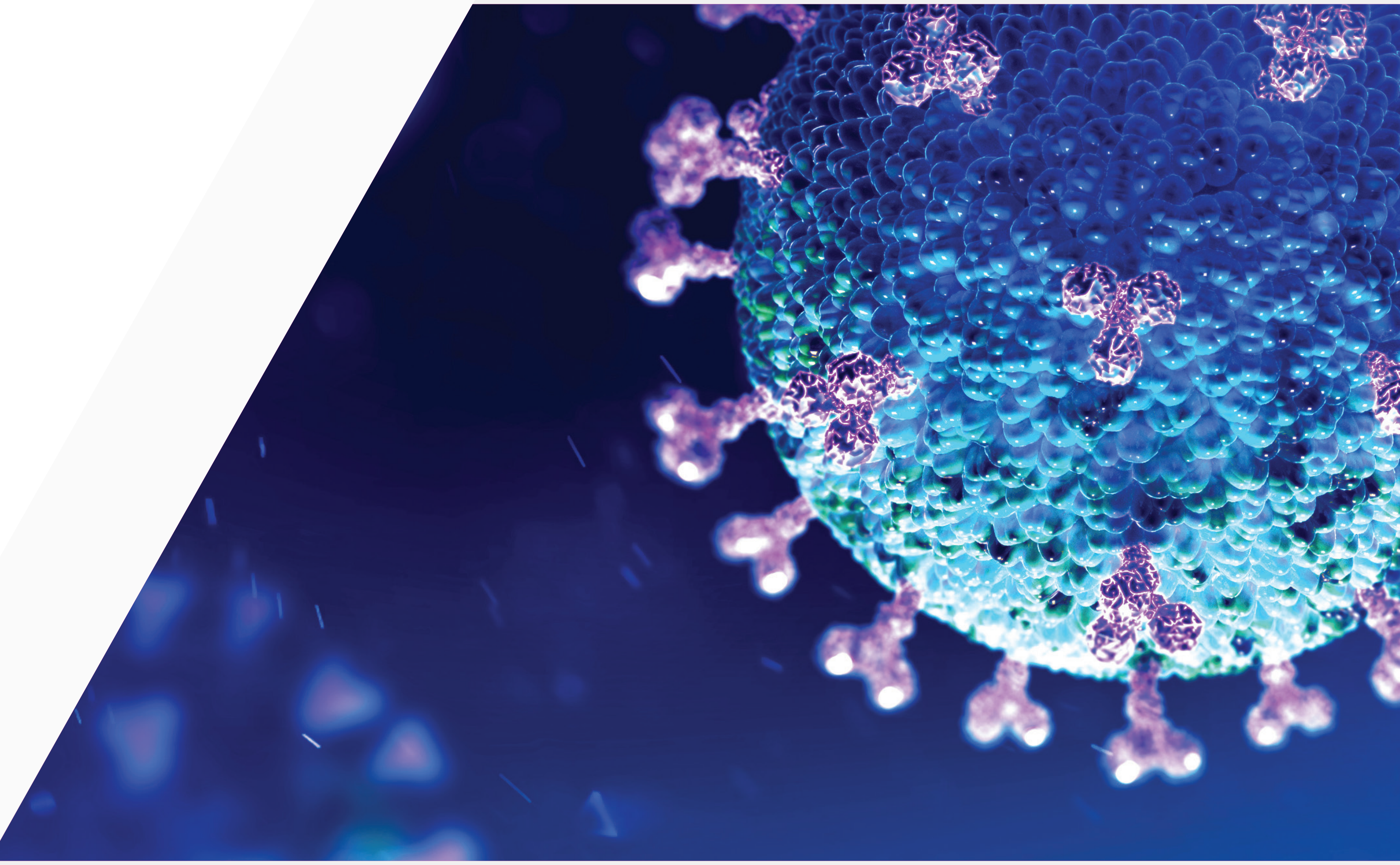
Some collaborative funding opportunities are no longer accessible due to Brexit. Brexit might have potential indirect effects on organisations if their customers are negatively affected by it (effect from the SC into previous tiers). Brexit might add another layer to the uncertainties regarding the future business landscape.

In general, it is believed that the focus of policymakers – in the next couple of years – will be tilted towards dealing with Brexit, which may hinder the progress required in other areas such as decarbonisation and "technologies will probably be moving faster than regulation" (Interviewee 7).

However, Brexit has brought about positive impacts as well; it is believed that now is the time to **increase local content** and companies around the UK are increasingly considering the option of local sourcing. In addition, some companies are even considering diversification/entering new markets and move existing engineering/manufacturing capability to other growth sectors. Some examples in this regard are as follows:

"One measure to mitigate Brexit was why we went into the DER (Driving the Electric Revolution) Grant with WMG, so we could really look at the supply chain, our suppliers and where we could get our product from internally within the UK" (Interviewee 3)

"There are plenty of companies that could convert [...] a company came to us and said: We can't do any of this stuff. We stamp stuff. So how do we play in batteries?" (Interviewee 10)



4. Identifying strategic SC opportunities

4.1. How can resilience be built in the low carbon sector?

Through the data collection process, various ideas in relation to building resilient low carbon SCs were identified. These insights have been clustered into the following groups:

- **Prioritising the right technology**
- **Focusing on the customer**
- **Improving the infrastructure**
- **Fitting existing organisations into low carbon SCs**
- **Upgrading skills**
- **Building collaboration between stakeholders**
- **Promoting flexibility**
- **Recycling and focus on circular economy principles**
- **Redefining funding opportunities**

4.1.1. Prioritising the right technology (or technologies)

Prioritisation must be explored among technologies with known application and a commercially proven status. A specific area of concern in this regard was the prioritisation of sectors and consequently, the prioritisation of sector-specific technologies:

"[…] when we want to achieve net-zero, we think of overall country level but each sector will not be net-zero; some sectors will be positive in emission, some will be negative in emission. And if the electricity sector is required to produce negative emissions because it's the most flexible out there, then ***some technologies will need to be prioritised****"* (Interviewee 5)

It is becoming increasingly important for the Government as well as different stakeholders to focus on investments that deliver true value to the nation. However, besides comparing different technologies, the focus should also be tilted towards listening to and understanding the customer. Creating the business case is important; however, customers' support and demand can contribute to a success story. As such, the desirability of a technology (to what extent is this technology needed?) should also be investigated.

"We should ***focus on business models and consumer behaviour*** *[…] Do minor freight companies have the money to invest in EVs or hydrogen vehicles?"* (Interviewee 7)

4.1.2. Focusing on the customer and generating customer demand

Understanding the customer is critical to the success of any innovation/technology/business; increasing customer confidence in low-carbon technologies and services is a priority. Since most of these technologies are still in their infancy, an appropriate communication method is required to disseminate their benefits and target the appropriate audience. Communication with founders, who are typically visionaries, is not the same as communication with more practical users in the mainstream. As a result, communication to the general public should emphasise the problems that this new technology can solve, as well as quantifying and contrasting the benefits so that it is easy to distinguish between innovative/green and conventional technologies.

Similarly, it is critical to analyse customers' interactions/experiences with a specific technology so that improvements can be implemented later. Analysis should also be conducted to determine the price points at which various customer segments are willing to spend in order to adopt more sustainable technologies/services (for example, as mentioned in the previous section – 'Do minor freight companies have the money to invest in EVs or hydrogen vehicles?'). Once this is known, the government can look into how to tip the cost balance, possibly by implementing different strategies for different customer segments.

"There's a vastly higher rate of electric and zero-emission vehicles being used by people with company cars than by the average public and the reason for that is the Benefit in Kind rates incentives. The government has done some things to tip the balance on cost" (Interviewee 4)

With regard to the information presented earlier, another idea emerged: *"The only way we can attract new companies/investment to the Midlands is by* ***aggregating demand*** *and creating an ecosystem that's investible into"* (Interviewee 10)

As such, there is an interrelation between information sharing (communicating the business case), demand (understanding the customer), and market prosperity, which has the ability to generate more investment and wealth to a region.

4.1.3. Improving infrastructure: key for testing and future systems

Although much work is being done to electrify transportation, the anticipated high demand for power does not appear to be addressed in the same way. Interviewees stressed the importance of designing efficient energy networks capable of meeting the anticipated high demand. Creating infrastructure to support the testing and deployment of new technologies such as hydrogen, batteries, or waste processing plants, are other ideas that emerged. To be 'accepted', forward-thinking technologies must go through rigorous testing and validation processes. Once these technologies have been commercially proven, the government can step in and implement schemes/legislation to boost consumer confidence even further.

"We were appointed by the UK Government to work on a programme called Future Power Systems Architecture. We applied a system engineering approach and defined the functions to be implemented for the future power system. […] we need to make sure that the power network is not only fit for purpose now or in 2030, but also beyond that" (Interviewee 5)

"The UK has to have the ability and capacity to test new technologies […] investing in capabilities is one of the main areas to focus on [...] we need additional development capabilities to support hydrogen technologies and fuel cells" (Interviewee 2)

4.1.4. Fitting existing organisations into low carbon supply chains

A particular concern is how can existing organisations fit into low carbon SCs and how can organisations alter their products/services to promote cleaner sources of power. Some interviewees believe existing companies can transition easily with the right support. Implementing regional programmes to help firms transition into low carbon sectors and promoting their growth should be prioritised. Restructuring/building new sectors was also a topic that emerged with two main observations: small companies are more flexible, thus can have a presence in different sectors, and sectors should be built around large organisations because they can attract demand.

"We are looking at programmes to help companies move to sustainable markets […] we are helping companies look at solutions and technologies that could help to decarbonise […] we have projects looking at the design stage to reduce emissions, select materials that are sustainable or recycled, and we look at end-of-life solutions" (Interviewee 9)

"In order to be more resilient, we should be thinking about how we develop other sectors, how to restructure and how to support that restructuring […] smaller companies are more flexible because they are not locked in to a single sector. […] If you're looking to create a new sector, it's hard to do it without having those anchor organisations" (Interviewee 1)

In addition to helping companies fit into low carbon SCs, "converting some of the infrastructures we have around oil and gas over technologies like hydrogen" (Interviewee 9) could also help us to transition towards a low carbon economy. Key takeaways and recommendations regarding hydrogen as a big-picture solution are as follows:

- To investigate the use of hydrogen in the gas grid, an assessment of hydrogen compatibility with existing pipes and pipe infrastructure is required, as well as a life-cycle analysis of technologies utilising hydrogen and natural gas blends, and a techno-economic analysis that allows for the quantification of the costs and opportunities for hydrogen production and blending within the natural gas network. Such evaluations, as exemplified in Text box 1, should have funding available to explore this topic on a regional scale.
- Similar evaluations are required to investigate the use of hydrogen in the power sector. The costs of using hydrogen as a storage solution for "wasted" energy should also be considered. The emphasis should also be on the potential for integrating the gas and electric infrastructures and using hydrogen as a buffer.

An assessment of the advantages and disadvantages of key technologies, including hydrogen, can be found in Appendix 6.

The impact of electrification and other trends associated with the transition to a decarbonised economy will inherently impact organisations and as such, companies must prepare for future market conditions. Text box 2 refers to this challenge and highlights an example of good practice in relation to preparing for future market demands. Since the automotive SC is intersected by different complementary industries (i.e., steel, chemical, magnet, electronics), organisations should be encouraged to conduct similar assessments to understand and prepare for the implications brought about by the transition to a decarbonised economy.

Text box 1. Hydrogen as a big picture solution. Convert/develop the infrastructure to support the hydrogen economy

At present, a blend of hydrogen (20%) and natural gas is being used to heat 100 homes and 30 faculty buildings at Keele University in Staffordshire. This ground-breaking trial is built upon a two-year preparation period, concluding that "all appliances sold after 1996 must be able to sustain 23% hydrogen under current regulations". In addition, Northern Gas Networks and its partners are launching the world's first 100% hydrogen testing facility (in Buxton, Derbyshire) so that the UK can make a zero-carbon, hydrogen-based gas grid a reality (the implications of 100% hydrogen on the existing infrastructure are not available yet).

There are advantages to a mixed gas and electric infrastructure and hydrogen can serve as a buffer in cases when power is down. Research should address what a combined gas and electricity infrastructure would look like and what are the cost implications of building/repurposing an infrastructure that would support this vision.

Text box 2. Assessing and understanding the implications of the transition to a decarbonised economy (preparing for future market conditions)

The shift from internal combustion engine vehicles (ICEVs) to electric vehicles (EVs) is likely to have a substantial effect on the automotive SC. Companies are therefore faced with uncertainty: how will the shift from ICEV to EV affect future demand for the raw materials, components, and sub-assemblies they provide to the OEMs. A UK steel company that supplies wire rod to the automotive SC in collaboration with WMG has conducted a research to understand the implications of electrification in its future demand. Future wire rod demand was synthesised from scenario development, tear down data of ICEV and EV wire rod content, and interviews that outlined a potential shift in the company's product offering, to apply to EV market needs.

In supporting the power sector, hydrogen is one of the leading options for storing variable renewable energy; the absence of a viable storage solution for potentially large amounts of "wasted" energy could be solved by the introduction of a hydrogen transportation and storage solution.

4.1.5. Upgrading skills

When organisations have incentives to transition to a low-carbon economy, they will need employees with the necessary expertise. As a result, it is critical to future-proof jobs by implementing training and reskilling programmes. However, manufacturers will not invest in workforce upskilling (and infrastructure, machines, and other related matters) unless there is a clear demand for low-carbon technologies. Thus, once again, understanding the end customer and increasing customer confidence serves as an enabler in this transition.

"We need focused skills to ensure that low carbon technologies have good quality. But you would not make that investment if you don't know how much the demand for low carbon technologies is. Companies don't have a good estimate in this matter because the benefits are not clear and this is why demand is low" (Interviewee 5)

4.1.6. Building collaboration between stakeholders

In a decarbonised economy, encouraging collaboration and sharing best practises is critical. This could be improved by smart connected solutions and digitalisation, which would allow greater transparency. Higher education institutions should take the lead in ensuring public-private collaboration in developing and implementing the regional plan for low-carbon transition.

Furthermore, *"we should not always reinvent the wheel […] in a report an idea emerged about the resource recovery clusters that would interconnect supply chains and promote a network of resource recovery"* (Interviewee 6). Creating networks of clusters would mutually benefit all parties. However, coordination and communication are key elements in this regard (e.g., data and resources sharing) and thus, elements such as single point of information sharing for collaboration and digitalisation should be integrated into such networks.

4.1.7. Promoting flexibility

The concept of flexibility has emerged in relation to three areas: sector development and restructuring to allow greater interoperability, interoperability of specific technologies/applications, and an open mind approach to new technologies. The interoperability of technologies, with the idea that different sectors are increasingly interconnected, encourages coordination/standardization between different products and is an area that should be investigated. Similarly, different stakeholders must maintain an open mind to avoid unintended consequences for emerging technologies and to allow the development of innovative alternatives.

"The Government should make sure that whatever is implemented doesn't penalize others that don't fit strictly into the policy […] this could end up harming other technologies that have potential and can have unintended consequences for emerging technologies" (Interviewee 6)

"There is lots of focus on batteries but there is lots of potential in fuel cells as an alternative, particularly for long-distance, heavy-duty vehicles" (Interviewee 2)

"It's technologically vulnerable to promote and invest in one technology" (Interviewee 3)

4.1.8. Recycling and focus on circular economy principles

To meet the anticipated high demand for new technologies, the nation should evaluate whether it has the required raw materials to manufacture those technologies. The absence or scarcity of any material will represent a vulnerability for the market. This might even result in cost fluctuations; exploring the recyclability of materials could be a beneficial option to mitigate this. Design for repair/possible upgrading/re-use/disassembly/recycling is an important element is this regard.

"Without recycling, I think the industry will be very open to cost fluctuations […] getting access to rare earth materials, for instance, in a way that is cost-effective, is key to the supply chain and recycling gives you that option" (Interviewee 10)

4.1.9. Redefining funding opportunities

Multiple recommendations emerged regarding the restructuring of funding opportunities. Department-specific funding, for instance, can be an enabler of change. Although restructuring funding opportunities would be a first step towards exploring department-specific matters and perhaps boosting sustainable sourcing solutions, nationally accepted measures should be implemented to enable such initiatives. A poorly designed initiative that lacks certain details (e.g., border tariffs) might induce unsatisfactory consequences or might be misused.

"Funding needs to be department-specific. Procurement departments could investigate where they are getting their materials from [...] if you go to people that make the screws and bolts, do they have a big enough department to investigate why they are buying that material from that specific organisation? Is it because they've done it for 20 years?" (Interviewee 3)

Funding should be given to close the gap within the innovation process, potentially moving from grants to loans or similar mechanisms that can accelerate the mass commercialisation of low carbon technologies. However, traditional bank models do not seem to fit manufacturing SCs; existing funding models should be re-examined and restructured to fit low carbon sectors' needs.

"The traditional bank lending models don't fit manufacturing supply chains; return on investment is three to five years down the line and sometimes this is too late for some small companies […] There are very few people putting funding into programmes now and the attractiveness of manufacturing within those pitch environments is very low. The attractiveness lies in: Uber connectivity app, Business support app. Those are being pitched all the time because they're scalable and have a high return on investment" (Interviewee 3)

4.2. Governance and public policy options

Governments can create incentives, regulations, and taxes that encourage a shift away from polluting sources. Ideally, such approaches should be complemented with market-oriented approaches that encourage R&D and replace ageing technologies and systems with cleaner and more efficient alternatives. Figure 10 presents a summary of the main policy and opportunities that can support the growth of low carbon manufacturers in the region.

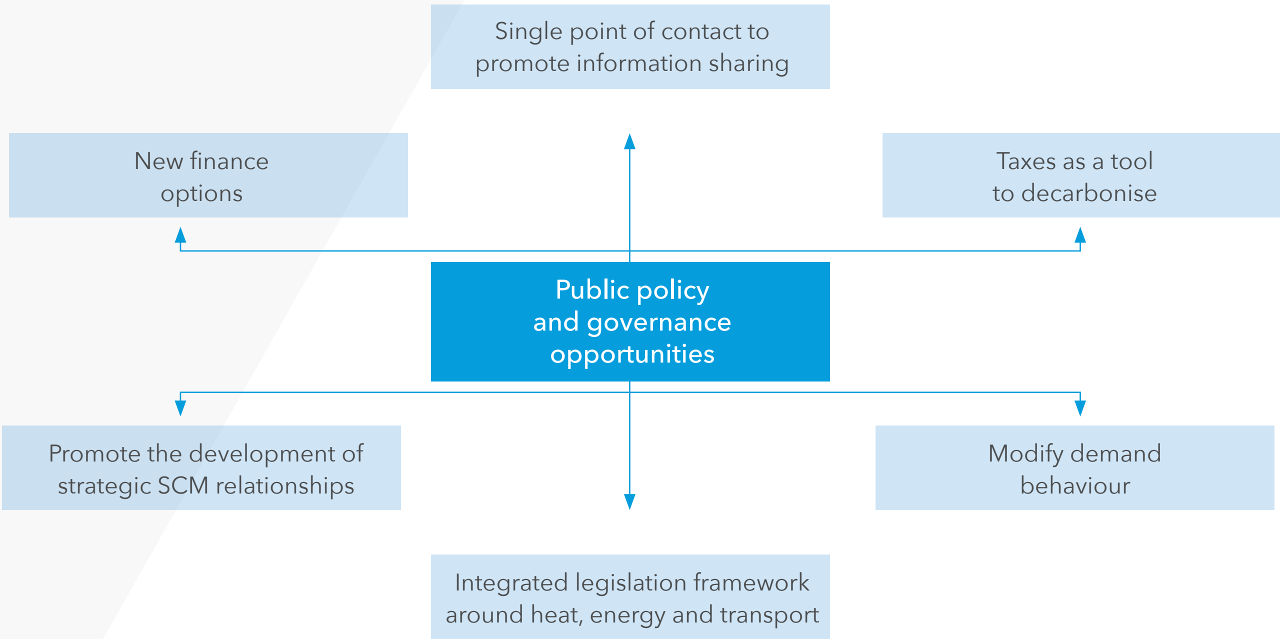


Figure 10. Summary of policy recommendations

4.2.1. New finance opportunities

Transitioning from traditional SCs to low carbon SCs will necessitate significant economic resources being invested in low carbon sectors. Therefore, green public finance opportunities can act as a catalyst for additional investments while also de-risking the early stages of the innovation process. Experts agree that these options should be adaptable and scalable to the needs of each organisation. The concept of a regional development bank arose in response to the need to assist and guide businesses in selecting the most appropriate funding mechanism. Although the government has already announced plans to establish a similar institution in the spring of 2021, interviewees suggested that it should take a regional rather than a national approach.

"If you're looking at a mechanism, you need like a regional development bank with business support managers (…) so it supports the redesign and the distribution of the grants" (Interviewee 3)

"There are incentives like green finance opportunities; offering business loans, preferential rate loans to buy capital equipment to be part of a low carbon supply chain is also potentially very beneficial and can grow things quite quickly" (Interviewee 4)

4.2.2. Promote the development of strategic SCM relationships

Given the risks associated with supplying certain components, such as REE elements (see Section 3.2 - sourcing), to manufacture low-carbon technologies, the development of SCs with mechanisms such as regulations for sustainable procurement and the implementation of recycling programmes are the first steps to be taken. Furthermore, the formation of SME clusters centred on specific capabilities is encouraged in order to foster ecosystems for new manufacturers. These clusters would add value to the low-carbon sector by strengthening capabilities, fostering leadership, establishing market niches, forging new business partnerships, and lowering aggregated footprints. The Leading-Edge Cluster Competition (LECC) in Germany, for example, contributed to funding potential leading-edge innovative clusters achieving great results, particularly in SMEs [24]; similarly, the Brandenburg Transport, Mobility and Logistics (VML in German) cluster comprises different organisations centred on the challenges of sustainable mobility, providing a platform for joint projects and supporting investments up to 40%, depending on the size of the company [25] [26]. Securing the appropriate ecosystem, as has occurred in various regions of Germany, will attract businesses to the Midlands and strengthen the sector's resilience.

"I think clustering is specifically beneficial for SMEs. Using a nature-based example: seagulls will follow a ship that's catching fish because there's value there and actually the smaller feeders will benefit greatly from being around that ship (…) Around big OEMs, SMEs would gain expertise and have more opportunities" (Interviewee 4)

4.2.3. Single point of contact to promote information sharing

Collaboration has been pointed out as one of the main factors to build resilience in the region. As a result, establishing a single point of contact to encourage information sharing between organisations appears to be an advantageous policy. Organisations want an accessible and simple platform to learn about various schemes and assistance mechanisms, as well as to find partners for different projects. Midlands Engine, HVM Catapult, and D2N2 Growth Hub could all play important roles in this regard. These organisations could also serve as a manufacturing marketplace/hub, allowing businesses to connect with potential suppliers and customers in order to develop and test new technologies.

4.2.4. Taxes as a tool to decarbonise

Fairly set carbon incentives and taxation systems on different industries using a system-level approach could play a twofold role in both incentivising customer demand and reducing cash flow pressures for organisations in their R&D stages. These measures have already been implemented in the development of the aeronautical sector in Mexico [27] but stakeholders need to consider a systemic approach to avoid unintended consequences on different sectors. In addition, carbon pricing and emission trading schemes could help to assess the performance of the different manufacturers and incentivise a faster transition into a low carbon economy. It has been argued that complete traceability of carbon emissions should be encouraged to have a stronger system [21], with the potential inclusion of carbon border tariffs to prevent any risk of carbon leakage[4].

[4] The possibility that, due to sustainable sourcing requirements and costs of climate policy in the UK, companies will relocate and/or source from countries with no or limited climate policies in place

"Once we can track embodied carbon, we can agree on border tariffs as well as carbon pricing" (Interviewee 9)

During one interview, the concept of green shoring emerged. This would entail not only the use of locally available talent and minimal travel, thereby contributing to a "greener" footprint, but also a sustainable sourcing strategy based on the emissions footprint of suppliers. However, a national accounting norm or standard must first be accepted and implemented to enable organisations to evaluate suppliers based on common characteristics. To deter businesses from relocating and/or sourcing from countries with no or weak climate regulations, policymakers should carefully evaluate green shoring options and ensure that mechanisms are not poorly designed.

4.2.5. Modify demand behaviour

There are two fundamental ways for the population to transition to a low carbon economy: voluntarily or through coercion. While some initiatives aim to discourage consumers from purchasing/installing environmentally harmful products (e.g., a ban on diesel cars), more sustainable alternatives remain prohibitively expensive, and more should be done to stimulate demand. Similarly, additional prohibitions on carbon-intensive technologies such as gas central heating boilers or road pricing could be implemented. To expedite this transition, incentives should be implemented to lower the cost of products such as electric vehicles and heat pumps. Local authorities have an important role in communicating the benefits and importance of implementing low carbon technologies [28].

4.2.6. Integrated legislation framework around heat, energy and transportation

In general, it is expected that processes and regulations will need to be simplified to lower the sector's barriers. While electricity costs (particularly transmission costs) are the primary target, grey areas surrounding carbon fuel recycling must also be addressed in order to create a set of rules that provides certainty for businesses. New standards and sectoral coordination should be implemented to create an approach that is tailored to the needs of heat, energy, and transportation [28]. Because these three are inextricably linked in the coming years, careful planning should be undertaken to ensure a clear path for the region. Hydrogen is a large-scale decarbonisation solution (see Appendix 6) that should be addressed in the integrated legislative framework.

"Energy, heating, and transportation: we should see them as a part of a bigger system. All of these sectors need to work together" (Interviewee 5)

offering business loans, preferential rate loans to buy capital equipment to be part of a low carbon supply chain is also potentially very beneficial

5. Conclusions, limitations, and recommendations

The low carbon value chain is comprised of multiple industrial and service SCs, each of which has significant potential in terms of revenue, employment, and installed capabilities. As this research has revealed, low carbon SCs are intersected by a variety of sectors, including R&D, vehicle manufacturing/distribution/sales, energy platforms, charging infrastructure components, and services. However, there are additional associated chains, such as electronics, magnets/rare earth materials, and chemicals, that contribute significantly to the development and commercialisation of low carbon technologies but were not considered in this research.

Although the Midlands is considered the UK's industrial heartland, the region's accelerated transition to a decarbonised economy and SCs is hampered by a number of vulnerabilities. Furthermore, due to the COVID-19 pandemic, 2020 was a year unlike any other, and the new year has far from returned to normal. Also, Brexit has exposed the country to a new set of challenges.

Specifically, planning has been an issue during the pandemic, as well as Brexit, due to the constantly changing environment and changes in demand patterns. This period also resulted in a lack of available cash flow. However, 2020 has also seen new partnerships between the private and public sectors. This period has placed a new emphasis on relationships. **Moving forward, the government should set the agenda and the regional facilitators (including pan-regional partnerships, LEPs, universities, chambers of commerce, research centres, and think tanks) should embrace this view, encourage collaboration between different stakeholders, and promote collectivistic values that would accelerate the transition towards low carbon and national prosperity.**

For this reason, creating networks of clusters that promote collaboration between different players would mutually benefit all parties and would promote the transition to low carbon. However, coordination and communication are key elements in this regard (e.g., data and resources sharing) and thus, elements such as **single point of information sharing and digitalisation** should be integrated into such networks. An existing regional facilitator could take the lead on this role. It is becoming increasingly important for the Government, as well as different stakeholders, to focus on investments that deliver true value to the nation. Thus, prioritisation must be explored among technologies with known application. However, besides comparing and contrasting different technologies, the focus should also be tilted towards listening to and understanding the customer. **As such, further research should tackle this issue through the lens of feasibility, viability, as well as desirability.**

In this regard, such technologies/innovations will only become desirable once their benefits are communicated in an appropriate manner to the public. The aggregated demand would have a further positive impact on the market that would be manifested in more investments coming to the region/country. However, preparing for the anticipated high demand for power and technologies is essential. A particular source of concern is whether the country has the raw materials needed to manufacture these technologies/components. The absence or scarcity of any material will represent a market vulnerability. As a result, the following actions are suggested to hasten the transition to a low-carbon economy and SCs:

- **understand the customer and communicate the benefits of new technologies**
- **future-proof power networks and related infrastructure**
- **develop infrastructure to support the testing and deployment of new technologies**
- **convert and fit existing companies and infrastructure into low carbon SCs**
- **develop and restructure sectors to allow greater interoperability between technologies**
- **upgrade skills to lead the low carbon transition**
- **promote circular economy principles to gain access to materials in a cost-effective way and mitigate predicted cost fluctuations (and save the planet)**

A topic that deserves particular attention is public policy. This can be a powerful instrument in promoting and developing low carbon SCs. However, its implementation is not without potential peril. As such, a poorly designed initiative that lacks details regarding responsibility, method or definition might induce unintended and/or unsatisfactory consequences or might be misused. Among the respondents, the following recommendations emerged regarding public policy options:

- **develop and restructure funding opportunities:** implement green finance opportunities, restructure loan schemes, implement preferential rate loans to buy capital equipment, develop a Regional Development Bank with business support managers to reduce the complexity of funding streams.
- **establish a single point of contact to promote information sharing:** information sharing of different grants so that companies are aware of different options.
- **implement taxes as a tool to decarbonise:** fairly set carbon incentives and taxation systems on different industries (system level approach), carbon pricing and emission trading schemes with border tariffs once a nationally accepted accounting/emission reporting system is implemented.
- **alter demand behaviour:** public sharing of green credentials for products/services (similar to the traffic light chart on food), road pricing and incentives to leave cars at the outskirts of a city or accelerate adoption of new technologies, restrictions on supply and demand and ban on purchasing/manufacturing of certain technologies.
- **update/generate legislation framework around heat, energy, and transport:** develop new standards and sectoral coordination between heat, energy and transport, generate schemes or legislation in relation to a recycled carbon fuels approach (currently this is a grey area).
- **promote strategic SCM relationships:** implement a framework and regulations for sustainable procurement and green shoring, develop SME clusters around specific capabilities to create an ecosystem for new manufacturers.

The recommendations in this report can help the region make a successful transition to a low-carbon future.

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7. Appendices

Appendix 1. Desk-based research

Collecting the data

In order to identify and portray the current state of low carbon supply chains in the Midlands, data has been collected from **CrunchBase** (the world's most comprehensive database on high-tech companies), **Fame** (UK and Ireland Company Database), and the **web** (Department of International Trade and Made in the Midlands).

In comparison to other databases, Crunchbase has data on both people and companies, showing the different founders or investors involved in the companies. However, it is argued that only information from the most successful firms is available at Crunchbase, and it is unknown whether more information regarding the smallest investments is presented or not considered as a potential bias[5]. Similarly, Fame reports a wide range of characteristics (mainly those that are available in a firm's annual reports/accounts), but it is argued that the platform's coverage is limited, especially in relation to small firms. Furthermore, Fame data relies on information collected on companies registered at Companies House in the UK; *"This means that data is often up to two years old […] and only large companies are obliged to report employment, turnover and assets but medium and smaller companies don't share this data"*[6].

As a result, one limitation of the current desk-based research is related to the selection of the biggest and/or most popular organisations in the region, reducing the size of the analysed network. It was overcome by the use of the web in general, but this adds another limitation related to companies with online presence, excluding those which do not have a website or present outdated information.

Companies were selected based on the low carbon definition from Section 2.1, including those involved in economic activities that deliver goods and services to energy and transport industries, with a presence in the Midlands. Figure 11 presents the criteria and keywords using during the searching process. Companies that were identified in any of the mentioned databases were included in a personalised spreadsheet for the analysis part.

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[5] For more information please see: The future of entrepreneurship data – getting to know CrunchBase – Ewing Marion Kauffman Foundation | Kauffman.org)

[6] For more information please see: Aston University matching of BSD and FAME data (publishing.service.gov.uk)

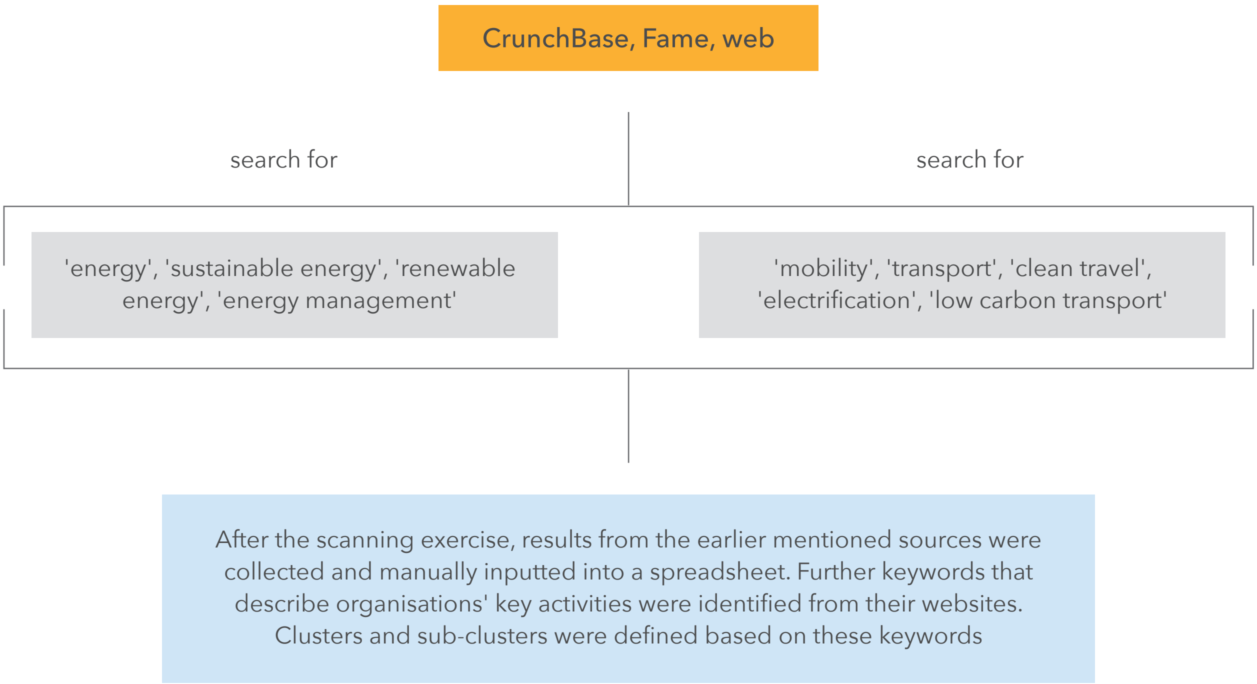

Figure 11. Methodology

Analysis stage

The research team analysed the organisation's website and establishes a series of keywords that represent its main activities and purpose based on its current content, reports, insights, etc. A second round of analysis was done to establish common keywords and avoid duplication (e.g. transport/transportation). After arranging the data in the right format[7] (see Figure 12), two series of statistical analysis were run in Gephi (an open-source network analysis and visualization software package). First a ***network diameter analysis***[8] was performed in order to adjust the size of the nodes. Betweenness centrality (in the network diameter analysis) is an important measure of the node's influence within the whole network; this shows how often the node appears on the shortest path between any two randomly chosen nodes in a network.

After this first analysis, a ***community detection algorithm***[9] was applied to identify the presence of distinct communities within the network. By running this statistic, those nodes were identified that are more densely connected to one another than to the rest of the nodes in the network.

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[7] For Gephi to read data, two separate datasheets need to be created: a "nodes" sheet and an "edges" sheet. In the nodes sheet each node is assigned a unique Id. In the edges sheet all relations between nodes are expressed as relations between Ids.

[8] Diameter, D, of a network having N nodes, is defined as the maximum shortest path between any two nodes in the network

[9] Gephi implements the Louvain method (Louvain community detection algorithm), available from the Statistics panel.

Appendix 2. Participants in interviews and focus groups

Table 3 List of interviewees

Code	Primary Focus	SC stakeholder category
I1	Energy	Knowledge provider
I2	Mobility	SC owner
I3	Mobility	SC owner
I4	Mobility	Knowledge provider
I5	Energy	Knowledge provider
I6	Energy	SC owner
I7	Mobility	Policy makers
I8	Energy & Mobility	Knowledge provider
I9	Energy & Mobility	Knowledge provider
I10	Mobility	Advisors/Facilitators

Table 4 List of participants in focus groups

Code	SC stakeholder category
Focus group 1	Knowledge provider
	Knowledge provider
	Knowledge provider
	Knowledge provider
	SC owner
Focus group 2	SC owner
	Knowledge provider
	Knowledge provider
	Advisors/Facilitators

Table 5 List of participant organisations (interviews and focus groups)

Participant organisations	
Advanced Propulsion Centre	Kew Projects
Aston Business School	Midlands Future Mobility
Birmingham Energy Institute	Pallite Ltd
De Montfort University	Ricardo Automotive & Industrial Consulting
Energy Systems Catapult	RIFT Technology Ltd
GBSLEP	The Open University
HORIBA MIRA	Transport for West Midlands
HVM Catapult	Warwick Manufacturing Group

Appendix 3. Interview questionnaire [10]

Understand the business

1. Can you tell us about your organisation's mission and how this relates to low carbon and sustainability-related concerns?

Value creation + Supply Chain mapping

1. How does your organisation create value in the region? How are your products/services/technologies contributing to carbon reduction efforts?
2. What percentage of your customers is from the UK? Where are the rest of your customers from?
3. What percentage of your suppliers is from the region/country? What are the main products that you source from local suppliers? From which part of the world do you source your raw materials/most critical components? Is there a specific reason for that?

Vulnerabilities

1. What are the main supply chain vulnerabilities that affect your organisation?

Disruptions

1. How did Covid-19 impact your organisation, activities, and supply chain? What are the new actions already taken in response to any of these events?
2. How did Brexit impact your organisation, activities, and supply chain? What are the new actions already taken in response to any of these events?
3. Does your organisation have a standard response to disruptions? If applicable, how did you alter your standard response to disruptions in order to cope with Covid-19/Brexit? Were there any differences between your response to Covid-19 and Brexit?
4. Apart from the earlier mentioned events, were there other disruptions that your organisation has encountered in the past 5-10 years? Were the responses different in these disruptions?

Risk Management

1. Does your organisation have a formal risk management process?
2. Can you please point out some initiatives/measure that your organisation implemented in order to mitigate the previously mentioned challenges and disruptions? Have these initiatives been proven effective?

Building resilience

1. When thinking about the industry you are operating in, what do you think businesses/organisations can do to increase low carbon supply chain resilience, specifically in the Midlands/UK?
2. If you had to choose three main areas to focus on and/or invest in to build supply chain resilience, what would these three areas be?

Governance

1. Is your organisation familiar with the Government's green industrial revolution? If so, how does this agenda influence your organisation? Have you taken any actions/did you plan accordingly?
2. Did your organisation participate/is interested in participating in any Government-funded programmes supporting the net-zero strategy?
3. Who do you think are the main stakeholders/institutions that should initiate change in the current market in order to accelerate the transition from a conventional supply chain to a low carbon supply chain?

Public policy options

1. How do you think local and national governmental institutions can promote the development of low carbon supply chains?
2. If you could suggest a mechanism of government support for enabling low carbon supply chains, what would that be? (i.e., tax based mechanism, obligation systems, fixed price feed-in systems, etc.)

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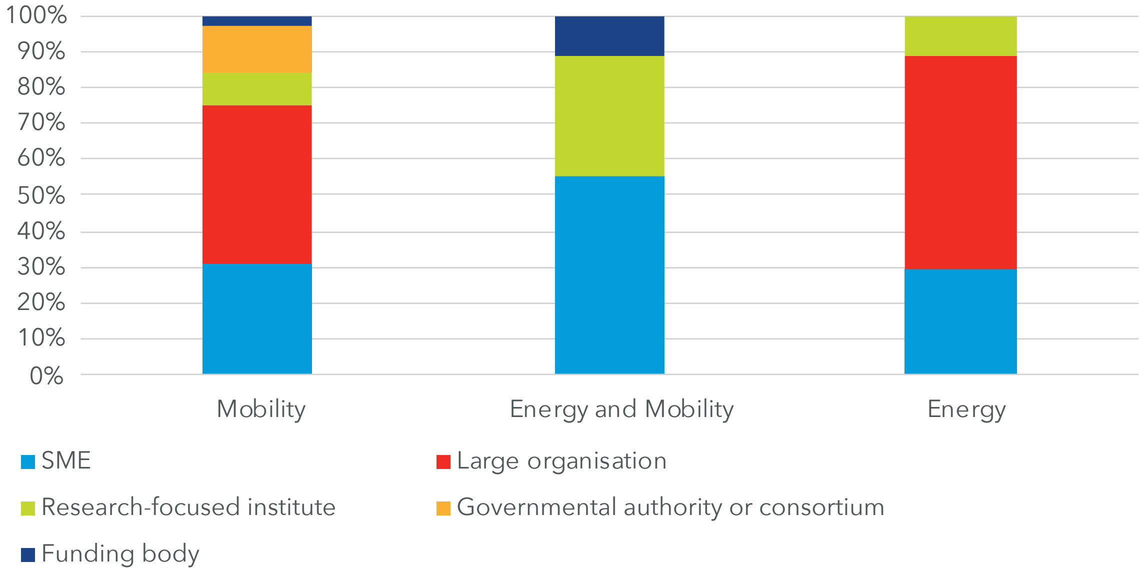
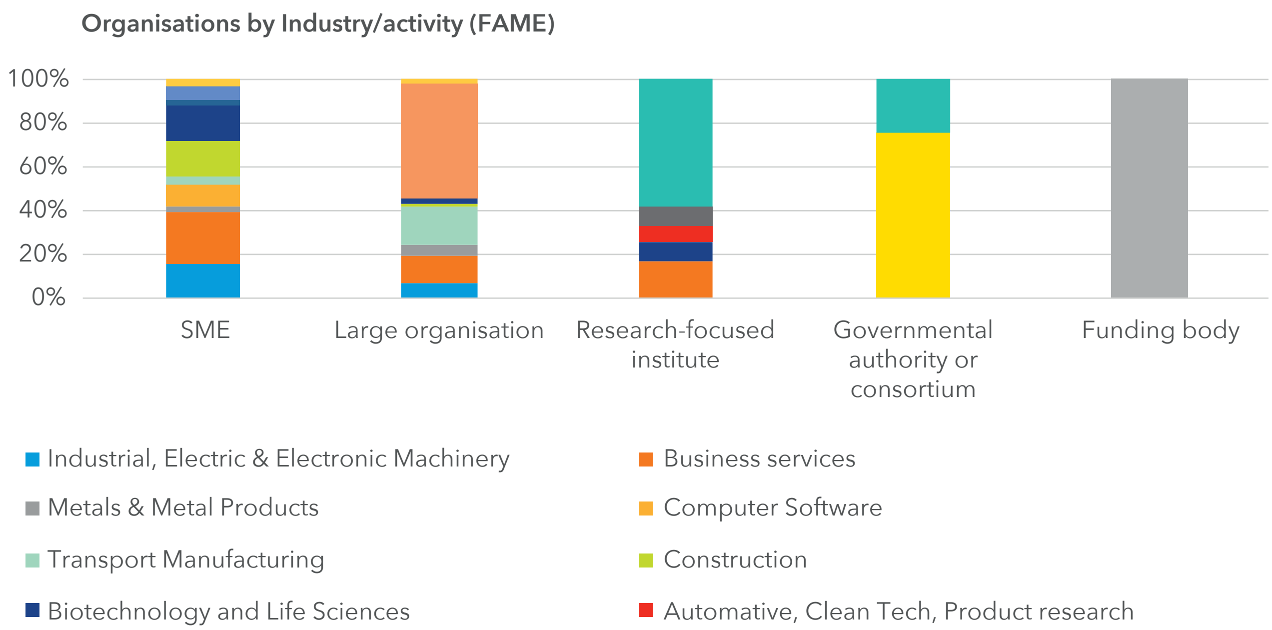
[10] Questions were adjusted according to the type of stakeholder category represented by the interviewee

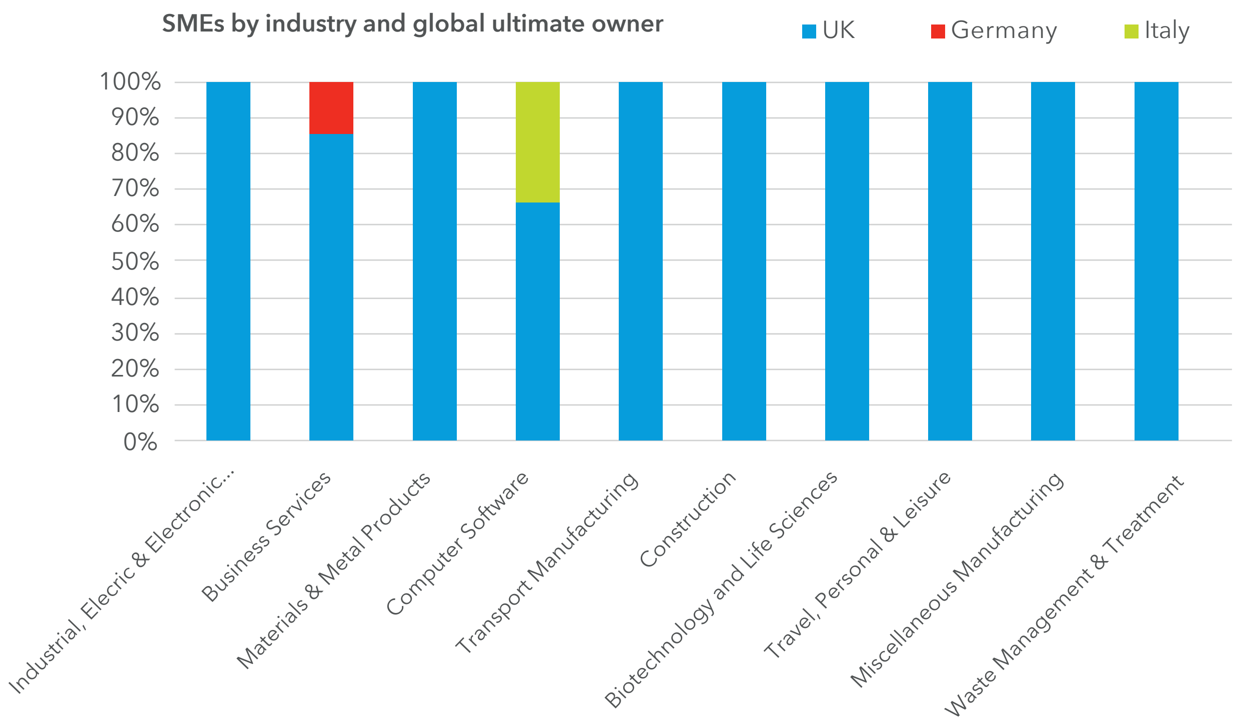
Appendix 4. Low Carbon and Environmental Goods Study – data Analysis

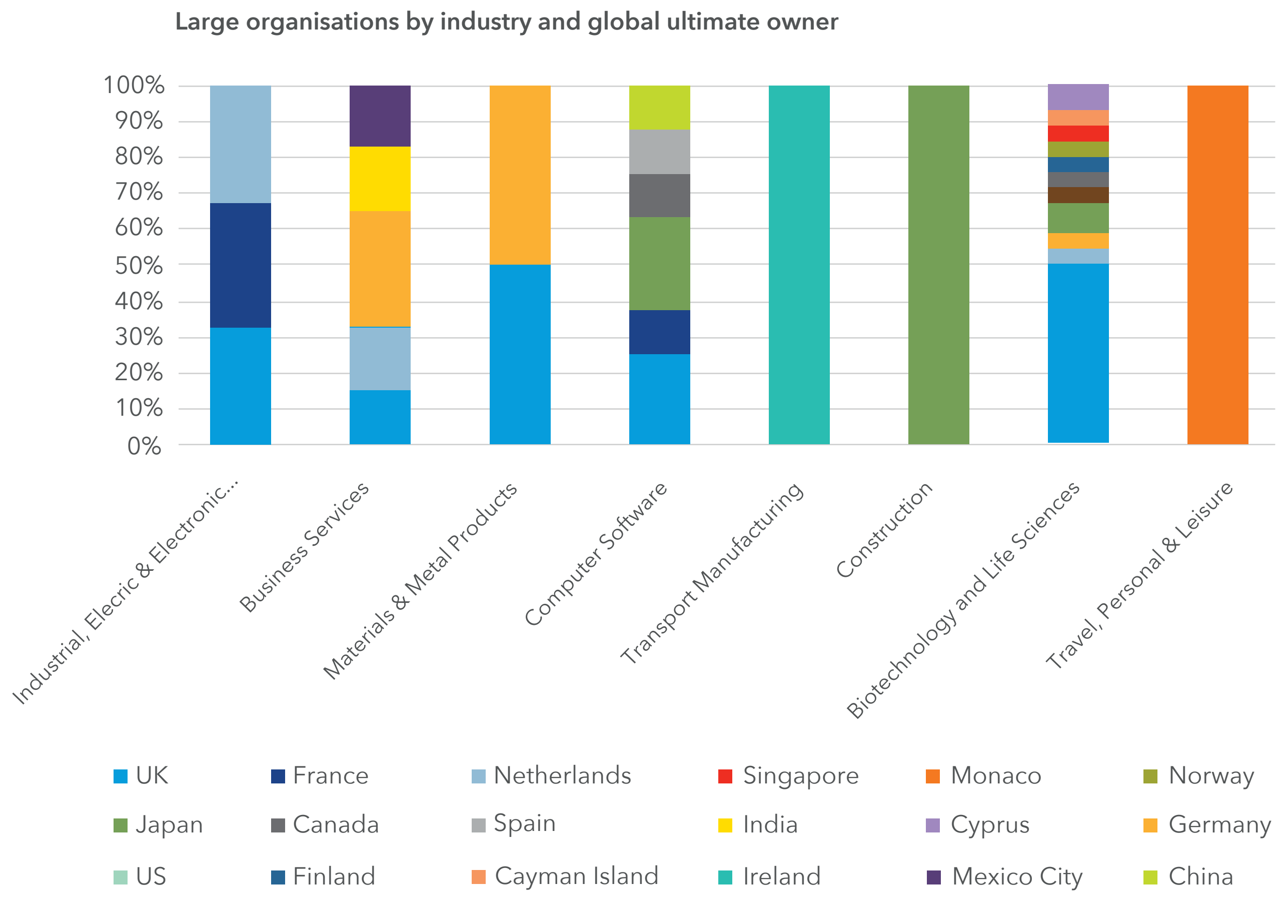
		Sales £m	#Companies	#Employees
Environmental	Air Polution	143.2	56	1,057
	Contaminated Land	143.3	58	1,061
	Environmental Consultancy	179.9	71	1,329
	Environmental Monitoring	38.0	15	280
	Marine Pollution Control	27.7	11	205
	Noise & Vibration Control	79.5	31	585
	Recovery and Recycling	1,452.5	584	10,726
	Waste Management	1,769.7	682	13,059
	Water & Waste Water Treatment	2,014.9	775	14,859
Low Carbon	Additional Energy Sources	234.7	93	1,732
	Alternative Fuel Vehicles	1,472.3	586	10,834
	Alternative Fuels	3,761.4	1,584	27,783
	Building Technologies	3,995.6	1,558	29,520
	Carbon Capture & Storage	90.3	36	667
	Carbon Finance	133.9	65	440
	Energy Management	559.7	222	4,135
	Nuclear Power	5.4	23	176
Renewable Energy	Biomass	1,943.2	774	14,392
	Geothermal	1,163.0	460	8,596
	Hydro	74.4	29	547
	Photovoltaic	2,773.4	1,075	20,530
	Renewable Energy General Consultancy	122.8	49	909
	Wave & Tidal	4.1	2	30
	Wind	4,373.1	1,745	32,364

Appendix 5. The nature of organisations included in the supply chain mapping exercise






SMEs by industry and global ultimate owner
UK
Germany
Italy
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Industrial, Elecric & Electronic...
Business Services
Materials & Metal Products
Computer Software
Transport Manufacturing
Construction
Biotechnology and Life Sciences
Travel, Personal & Leisure
Miscellaneous Manufacturing
Waste Management & Treatment


Large organisations by industry and global ultimate owner
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Industrial, Elecric & Electronic...
Business Services
Materials & Metal Products
Computer Software
Transport Manufacturing
Construction
Biotechnology and Life Sciences
Travel, Personal & Leisure
UK
France
Netherlands
Singapore
Monaco
Norway
Japan
Canada
Spain
India
Cyprus
Germany
US
Finland
Cayman Island
Ireland
Mexico City
China

Appendix 6. Assessment of different technologies

VEHICLE TECHNOLOGIES: ENERGY STORAGE SYSTEM (ENERGY CARRIER) [11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22]	
1. BATTERY ELECTRIC	
Advantages	**Disadvantages**
▸ **better suited for passenger cars** ▸ **rechargeable batteries are more familiar than hydrogen fuel cell:** they are used in computers, cell phones, automobiles ▸ there are **no direct emissions of air pollutants** ▸ charging cars **can make use of an existing, extensive refuelling infrastructure - the national grid** ▸ when electric cars are charged **using renewable energy, they can help lower the carbon footprint of the transport sector** ▸ **if lithium batteries are recycled or reused for other purposes, the EV will be a more sustainable solution** than the hydrogen alternative ▸ **electricity offers a large reduction in noise at lower speeds** (although this may pose a risk for pedestrians and cyclists) ▸ UK's first car **battery 'Gigafactory' to be built; producing batteries with a capacity of as much as 30 gigawatt hours (GWh) a year**	▸ **batteries have low energy density and low range** (energy per mass or volume; the weight-energy density of batteries is about 1/20 that of gasoline and about 1/10 that of hydrogen) ▸ **low speed of charge** (usually an hour or two) ▸ **concerns about the provenance of some raw materials** used in battery manufacture, such as cobalt and nickel (e.g., unethical mining practices, child labour, environmental risks) ▸ **infinite quantities of raw materials** (not enough lithium in the world to create a battery electric vehicle for everyone; lithium is only located in a handful of places) ▸ **some local distribution grids would need upgrading** in the case of a significant switch to EVs ▸ **additional infrastructure is required to install charging points** at the home and public charging stations ▸ the **large purchase cost of battery electric vehicles** compared to petrol, diesel, or hybrid vehicles ▸ **batteries become too heavy** when increasing the size to enable greater travelling distances ▸ **concerns arise if the battery is misused and is kept beyond its designated age** ▸ **actual real-world battery durability over the lifetime of the vehicle is a relative unknown** ▸ **hot climates accelerate capacity los**s ▸ **insufficient information is available about how batteries age under different climates and usage patterns**

2. HYDROGEN FUEL CELL	
Advantages	Disadvantages
▶ **better suited to heavy-duty transport, aviation, and shipping** ▶ **hydrogen is available in infinite quantities** (via electrolysis/water splitting) ▶ **fast refuelling** (3-5 minutes) ▶ **high range** (the energy density of hydrogen gas is nearly that of gasoline when the efficiency effect is included; circa 2.5 kWhr/kg while current Li-Ion batteries store far less than this, about 0.15 kWhr/kg) ▶ **hydrogen can be stored over long periods** ▶ **hydrogen technologies are almost 100% recyclable** and are much easier to handle at end-of-life than batteries ▶ fuel cell enjoys similar qualities to the internal combustion engine in that i**t can conquer great distances with only the addition of extra fuel** ▶ **no direct emissions of air pollutants, with only water vapour being emitted** ▶ **produced with renewable electricity, it is a zero-emission energy carrier** ▶ **the UK has unlimited potential for renewable hydrogen production from offshore wind** ▶ **the world's largest electrolyser plant, under construction by the United Kingdom's ITM Power,** is expected to produce 1 GW per year (under construction in Scotland)	▶ **fuel cells are less familiar but not totally new:** they are used to power most submarines and spy-planes ▶ hydrogen fuels will remain **more expensive than driving all-electric;** the reason: **more energy is required to produce them** (compared to electricity and charging) ▶ **lower efficiency** (due to high energy losses; around 45% of the energy is already lost during the production of hydrogen through electrolysis) ▶ **poor refuelling infrastructure** (hydrogen refuelling station: there are only 12 in the UK - and half of those are in the south-east) ▶ **most commercial hydrogen available is made by reforming fossil fuels,** such as gas, which is harmful for the environment ▶ **hydrogen is highly flammable, tends to escape containment and reacts with metals** ▶ **clean hydrogen production with renewable electricity is not yet as cost competitive as hydrogen produced from natural gas** ▶ **building a hydrogen infrastructure is expensive** (a refuelling station capable of reforming natural gas to hydrogen to support 2,300 vehicles costs over $2 million, or $870 per vehicle)

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3. INTERNAL COMBUSTION ENGINE WITH LOW-CARBON FUELS	
Advantages	**Disadvantages**
▸ **vehicles with internal combustion engines can be fuelled with low-carbon fuels** ▸ **implementing engine technologies can be some of the most cost-effective reduction measures and can be achieved in the short term** ▸ **fast refuelling** (3-5 minutes) ▸ **natural gas can be used in spark-ignition engines with modifications of a minor nature** ▸ **apart from the GHG reduction potential, using compressed natural gas (CNG) has air quality benefits** ▸ **the technology for using CNG in cars is mature** (with countries across Europe using them already – notably Italy, which has over 785,000 CNG cars and vans on the road) ▸ **biomethane (biogas) is produced from renewable sources such as food waste and manure** (it can achieve substantial GHG savings compared with petrol and diesel fuels) ▸ **use of biomethane in transport creates little or no land-use change emissions and does not compete with food production** ▸ **biomethane can be used in spark-ignition engines with only minor modifications and does not require any additional changes to the refuelling infrastructure** ▸ **biodiesel made from used cooking oil diverts a waste stream which can otherwise cause disposal problems, and results in very high GHG savings** ▸ **blends of up to 7% biodiesel can be used directly by vehicles without any modification to the refuelling infrastructure or vehicle engines** ▸ **next-generation biodiesel fuels are drop-in replacements for diesel fuel** (i.e. compatible up to 100% blends with current diesel engines; this removes the need for changes to the refuelling infrastructure and vehicles)	▸ **CNG has a high energy content per kilogram, but a low energy content per litre** (even with high compression levels, CNG vehicles require cylindrical storage tanks that can weigh four times as much as an equivalent full diesel storage tank) ▸ **because CNG is a fossil fuel, there is no further potential for reduction in direct GHG emissions beyond current levels** ▸ **there is minimal specific refuelling infrastructure for the use of CNG in automotive applications** ▸ **biomethane's disadvantages are much the same as for CNG (except those associated with being a fossil fuel)** ▸ **biomethane has low energy content per litre, and vehicles require cylindrical storage tanks that can weigh four times as much as an equivalent full diesel storage tank** ▸ **there are concerns that first-generation biodiesel produced from food crops, or on land that could otherwise be used for food (e.g. palm oil), could result in increased global food prices and could decrease biodiversity** ▸ **first-generation biodiesel is mildly corrosive and can degrade while in storage tanks** (when this degraded fuel is burned in an engine, it can corrode engine parts and leave deposits that plug pumps and other mechanisms) ▸ **next-generation biodiesel production processes are more expensive than those for first-generation biodiesel** ▸ **while HVO (a type of next generation biodiesel) is now in commercial production, volumes are low compared to first-generation biodiesel** ▸ **biofuels aren't as efficient or powerful on their own** (when they're blended with conventional fuels they can improve performance and fuel economy) ▸ **biofuels are not developed enough for mainstream use yet**

KEY TAKEAWAYS AND RECOMMENDATIONS REGARDING VEHICLE TECHNOLOGIES

- The transition to a decarbonised economy is likely to need all these technologies to some degree.
- Low-carbon fuels are an immediate solution, the underlying technology is relatively mature, and there is no need for additional changes to the refuelling infrastructure. Low-carbon fuels can act as a stop gap or filler that helps the country to transition to technologies that are not ready for mass commercialisation or are not yet affordable to the mass population.
- An ideal long-term solution would be a hybrid technology/mechanism that combines a battery for short commutes and a hydrogen fuel tank for long distances. (The Engineer notes that: "Hybridisation of battery and fuel cell technologies is…likely to be explored more widely").
- End-of-life and circular economy solutions and principles must be explored to tackle some of the challenges associated with raw material use in battery electric technologies.
- The UK has unlimited potential for renewable hydrogen production from offshore wind and appropriate strategies should be implemented in order to leverage on this.

HYDROGEN AS BIG-PICTURE SOLUTION[23, 24, 25, 26, 27, 28, 29, 30, 31]			
Hydrogen in gas grid		Hydrogen in power sector	
Advantages	Disadvantages	Advantaged	Disadvantages
▶ **hydrogen can be burned in boilers and cookers** (it can replace methane in the gas grid) ▶ **when hydrogen is burned it produces heat and water** (as opposed to carbon dioxide) ▶ **existing infrastructure (gas transport and gas storage) can be repurposed for hydrogen** ▶ hydrogen can be injected into existing modern gas networks with **no need for customers to change appliances or pipework** ▶ a certain proportion of hydrogen **can be blended with natural gas** ▶ there are **no chemical incompatibility issues** of note between hydrogen and the odorising compounds commonly used in natural gas ▶ **injection of hydrogen at concentrations of 20% or less is unlikely to have a deleterious effect on the gas network and most appliances** ▶ Kiwa Gastec assessed the infrastructure needed to facilitate the conversion: part way through an ongoing network upgrade, due to be completed by 2032, through which **the country's low and medium pressure distribution network is being replaced with polyethylene pipes – which, conveniently, are suitable for transporting hydrogen** ▶ Kiwa Gastec: utilising the existing gas network will significantly reduce the scale and complexity of the decarbonisation challenge ▶ Northern Gas Networks and its partners are launching the **world's first 100% hydrogen testing facility** so that the UK can make a zero-carbon, hydrogen-based gas grid a reality ▶ the UK has unlimited potential for renewable hydrogen production from offshore wind ▶ **the world's largest electrolyser plant is under construction by the United Kingdom's ITM Power**	▶ less certain whether the inclusion of hydrogen would have **any long-term effects on appliances** ▶ questions regarding **how hydrogen affects the pipelines it travels in** ▶ "hydrogen embrittlement" **can weaken metal or polyethylene pipes** and increase leakage risks, particularly in high-pressure pipes ▶ A further challenge is **how to carry out a conversion with minimal impact on end users** ▶ **there is no timetable for mandating hydrogen-ready appliances** (which are necessary in order to facilitate a network conversion; the earlier hydrogen-ready appliances are rolled out, the smoother the conversion will be) ▶ the main risk is that **insufficient volumes of hydrogen production are supported**	▶ **offshore wind and green hydrogen are "uniquely suited technologies" that could combine** to play a massive role in the global energy transition ▶ in supporting the power sector, **hydrogen is one of the leading options for storing variable renewable energy** ▶ **hydrogen could be used in gas turbines to increase power system flexibility** (gas is used today across multiple sectors, but it plays a major role in power generation) ▶ the absence of a viable storage solution for potentially large amounts of **"wasted" energy could be solved by the introduction of a hydrogen** transportation and storage solution ▶ can **store excess and low-cost renewable energy as hydrogen** for distribution via the gas networks to industrial, power, transport or domestic consumers ▶ **hydrogen can be synthesised from electricity** (as well as water) ▶ **there are advantages to a mixed gas and electric infrastructure** (it's an advantage to be able to heat your house and your food even if power is down; **hydrogen could serve as a buffer)**	▶ industry players see vast potential for combining large-scale turbine deployments with electrolysis, but **this requires investments in infrastructure** ▶ **a large amount of energy would be required to generate green hydrogen to replace natural gas** (required for generating electricity/power) ▶ **the planning system will need to be able to accommodate a large volume of applications for hydrogen production, storage, pipeline and other facilities** ▶ **it is not clear whether the planning system will be able to manage this in a timely manner** ▶ **not enough incentives to scale-up a hydrogen economy**

KEY TAKEAWAYS AND RECOMMENDATIONS REGARDING HYDROGEN AS BIG-PICTURE SOLUTION

- Hydrogen is a big-picture solution in transitioning towards a decarbonised economy, however, it appears that there are not enough incentives to scale-up a hydrogen economy. Implementing measures similar to Offshore Wind, such as Contracts for Difference would help in this regard.
- To explore the use of hydrogen in a gas grid and assess the associated financial requirements, the following research tasks should be considered: evaluation of hydrogen compatibility with existing pipes and pipe infrastructure, life-cycle analysis of technologies using hydrogen and natural gas blends as well as alternative pathways (i.e., 100% hydrogen), and techno-economic analysis that allows the quantification of costs and opportunities for hydrogen production and blending within the natural gas network as well as alternative pathways. Worth noting is that such evaluations, as evidenced above, should be carried out by a consortium of organisations specialised in specific fields that can complement one another. Funding should be made available to explore this topic on a regional basis.
- To explore the use of hydrogen in the power sector similar evaluations are required. Particularly, the possibility of a synergy between offshore wind and green hydrogen should be evaluated. The cost implications of hydrogen as a storage solution for 'wasted' energy should also be assessed. Focus should also be tilted towards the potential of integrating gas and electric infrastructures and the use hydrogen as a buffer.
- The UK has unlimited potential for renewable hydrogen production from offshore wind and appropriate strategies should be implemented in order to leverage on this.

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Appendix 7. Summary of the two focus groups

Overview of building SC resilience in low carbon SC in the Midlands

3 key SC challenges

1. Lack of visibility manifested in 2 ways: Complexity of global SCs, SMEs intergration, visibility of existing suppliers and the interconnection of these
2. Cost as driving force: making local SCs uncompetitive
3. Public awareness not stimulating demand

3 key actions to build SC resilience

1. **Collaboration** (circular-economy-related concerns)
2. **Infrastructure development** (especially for large companies.)
3. **Waste management**

3 things government (local/central) can do to help

1. Green finance opportunities
2. Tax incentives to improve public perception
3. Carbon procing and emission trading schemes

Overview of building SC resilience in low carbon SC in the Midlands

3 key SC challenges

- Uncertainty (Demand of low carbon technology)
- Finance
- Lack of knowledge (education)

3 key actions to build SC resilience

- Knowledge sharing
- Midlands Green Bonds, Bonus Malus
- Build capacity (education / workforce)

3 things government (local/central) can do to help

- Promoting collaboration universities & industry
- Public sector to take leadership rolw (market making capabilities)
- Investment / Regulation

Excellent transport and road links

- 1 hour to London by train
- Nearest airport - Birmingham International (approx 20 minutes by car)
- Nearest train stations - Coventry or Canley (approx 10-15 minutes by car)

Getting in touch

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