INNOVATION & RESEARCH CAUCUS

UK NET ZERO CAPABILITIES

Understanding the Net Zero Technology Market

IRC Report No: 032

REPORT PREPARED BY

Dr Lauren Tuckerman University of Glasgow

Dr Francisco Trincado-Munoz Oxford Brookes University

Dr Michalis Papazoglou Oxford Brookes University

Mr Jakub Janec Oxford Brookes University

Prof Tim Vorley Oxford Brookes University

UKRI Delivered with ESRC and Innovate UK

Contents

Authors

The core members of the research team for this project were as follows:

- Dr Lauren Tuckerman - Adam Smith Business School, University of Glasgow
- Dr Francisco Trincado-Munoz - Oxford Brookes Business School, Oxford Brookes University
- Dr Michalis Papazoglou - Oxford Brookes Business School, Oxford Brookes University
- Mr Jakub Janec - Oxford Brookes Business School, Oxford Brookes University
- Prof Tim Vorley - Oxford Brookes Business School, Oxford Brookes University

This document relates to IRC Project IRCP0024: Net Zero Capabilities of UK Industries

Acknowledgements

This work was supported by the Economic and Social Research Council (ESRC) grant ES/X010759/1 to the Innovation and Research Caucus (IRC) and was commissioned by Innovate UK (IUK). We are very grateful to the project sponsors at UK Research & Innovation (UKRI) for their input into this research. The interpretations and opinions within this report are those of the authors and may not reflect the policy positions of IUK.

We would also like to acknowledge and appreciate the efforts of the IRC Project Administration Team involved in proofreading and formatting, for their meticulous attention to detail and support.

About the Innovation and Research Caucus

The Innovation and Research Caucus supports the use of robust evidence and insights in UKRI's strategies and investments, as well as undertaking a co-produced programme of research. Our members are leading academics from across the social sciences, other disciplines and sectors, who are engaged in different aspects of innovation and research systems. We connect academic experts, UKRI, IUK and the (ESRC), by providing research insights to inform policy and practice. Professor Tim Vorley and Professor Stephen Roper are Co-Directors. The IRC is funded by UKRI via the ESRC and IUK, grant number ES/X010759/1. The support of the funders is acknowledged. The views expressed in this piece are those of the authors and do not necessarily represent those of the funders.

Cite as: Tuckerman, L., Trincado-Munoz, F., Papazoglou, M., Janec, J, Vorley, T., 2025 UK *Net Zero Capabilities: Understanding the Net Zero Technology Market*. Oxford, UK: Innovation and Research Caucus

Executive Summary

This report aims to answer the question of ‘what is the UK good at, in terms of Net Zero technologies?’ focusing specifically on the potential to generate economic value from Net Zero technologies. To answer this question, we explore secondary data sources, namely, patents, exports, and ‘real time’ investment data, using a range of analytical tools to understand the complexity of the UK Net Zero technology landscape.

We find that there are different strengths in the UK Net Zero technology landscape, with little crossover between insights generated by the different data types. For example, while the patent-based analysis suggests Tidal Stream, Offshore Wind, Carbon Capture, Utilisation and Storage (CCUS), Nuclear technologies, Smart systems and Building fabrics are strengths, the export data suggest Gas flaring emissions reduction, Environmental monitoring, analysis and assessment, Clean up/remediation of soil & water and Natural risk management is where the UK export strengths are. The real time data on the other hand, shows that a company signalling they use a particular technology in their company description does not increase their likelihood of funding.

The UK Net Zero technology landscape is characterised by a high level of diversity, complexity and remains siloed according to our industry space and technology/industry cluster analyses. However, there are energy technologies which are providing an anchor for Net Zero development, and broadly speaking, these have high level of economic activity across our measures, interacting with other industry sectors well. In addition, there is an opportunity for more diffusion of enabling technologies such as software, digital platforms and AI, as they are not reaching their full market penetration potential in the Net Zero technology landscape.

Encouraging broader integration of complex and specialised technologies across industries, and supporting firms to patent, export and see market opportunities for their technologies beyond their initial specialisms could bolster the economic benefits from Net Zero technologies in the UK. This might be achieved through targeted spinout support and accelerators programmes for Net Zero firms. Secondly encouraging a wider adoption of enabling technologies such as software, digital platforms and AI across the Net Zero landscape would further create capacity and capabilities to meet Net Zero goals.

Areas of future research that could deepen our understanding of the economic benefits of Net Zero technologies in the UK include: (1) exploring the relationship between grants and equity to better understand crowding out vs crowding in effects, (2) looking at the effect on turnover of use of particular technologies (as defined by mentioning them in a company description) (3) deepening our analysis into unusual combinations (or outliers) in the industry space and technology cluster analysis, (4) taking a deeper dive into energy to unpack the different economic benefits of particular technologies and (5) to breakdown technologies by their technology readiness levels to understand which technologies benefit from what support at different stages of their development.

1. Introduction

The UK 'green' industry has been estimated as providing £83.1 billion in Gross Value Added (GVA) to the economy over the financial year 2023-2024 (CBI, 2025). Technologies that combat greenhouse gas emissions (GHG emissions) are not only able to address a core environmental challenge but can provide vital competitive advantages to the UK economy. Supporting the development of Net Zero technologies sits within Innovate UK's vision of the UK being able to "prosper from being the fastest transitioning economy to Net Zero" (Innovate UK, 2022). Understanding which Net Zero technologies will unlock growth, while reducing GHG emissions is a key challenge to meeting this vision.

Innovate UK's Energy team initiated this project to understand the core question of 'what is the UK good at?" when it comes to Net Zero technologies that are likely to return an economic benefit. The aim of the project is to understand how existing data sources can be used to answer this question for horizon scanning activities for the team and broader Innovate UK colleagues interested in Net Zero technologies going forward.

This report provides the initial insights from the project analysis between September 2024-July 2025 focusing on existing methods of evaluating market potential of Net Zero technologies, and ways to build on them to understand current market potential. In particular, we explore data related to patents, exports, and 'real time' data.

Net Zero technologies are not straightforward to define, as the idea cuts across functions, industries and sectors. While the data sources used are complimentary in that they provide different lenses to answer the question posed, aggregation of the data is not possible due to the different classification systems used. Furthermore, while there are subtle differences in the measured used, it is also worth noting that patents, product complexity as it relates to exported products, and high growth firms as they are defined in the 'real time' datasets are likely to have a significant amount of crossover, meaning that understanding which of these attributes leads to success for the UK Net Zero technologies is a complex question.

2. Approach

The project focused on three lenses of answering the question "What is the UK good at in terms of Net Zero technologies: patents, exports and 'real time' data. We started by reviewing what methods were currently in use to evaluate the economic benefits of Net Zero technologies, reviewing existing papers and reports to understand the underlying data, what insights could be gained from the approach and the limitations of the approach. We understood that, while incredibly useful, existing methods typically focused on patent and export data leaving gaps in areas where patents may not have been awarded or applied for, as well as more 'real time' data and evidence of the internal market for Net Zero technologies. From this we undertook a deeper dive into data based on a financial database, Beauhurst, to address the timeliness, internal market dynamics and lack of patenting. We refer to this dataset as 'Real Time' data.

We created our sample Beauhurst dataset by including their CleanTech tag[1] and supplementing with the European Patent Office's climate change patent codes (see Appendix 1). Both of these classifications are wider in their remit than purely Net Zero. We had a series of considerations that informed our choice of dataset: firstly, we wanted to create a process in the real time data that was replicable for Innovate UK, who already have access to Beauhurst, secondly, we then relied on the data sources' classification system. As Net Zero technologies can be considered a subtype of clean tech, it was unsurprising that our sample demonstrated a high level of crossover with other classifications of Net Zero technologies. Furthermore, taking a wide sample of companies to ensure we were capturing technologies related to Net Zero and understand how the technologies might interact with other clean and climate technologies.

Our search parameters in Beauhurst resulted in data for 4,800 companies, reduced to 3,247 companies after initial cleaning which removed incomplete records and companies that were no longer active. Included in the dataset was a tag created by Beauhurst that was designed to identify potential 'high growth' firms.[2] To generate insights on technologies from our dataset, we cleaned the descriptions of the companies and prompted ClimateBERT[3] (Webersinke et al., 2022), a large language model, to generate a list of tags likely to be areas of technology development using Python. We cut off the identification of a technology at a confidence of 0.15. We then semantically grouped these tags using a clustering method before two of the research team and our Innovate UK project lead qualitatively cross checked the tags to create groups of technologies which were used in our analysis. During this process we also removed tags which were low frequency, did not provide a technology or relate in some way to climate, clean or Net Zero technologies. We used the technology groups and tags to create descriptive statistics of our data sample, as well as performing a series of statistical analyses on the data to understand the market penetration of technologies into industries, and the impact of flagging the use of a technology on equity and grant funding.

[1] Beauhurst's CleanTech tag is generated by manually tagging any company which is benefiting the environment through some form of technology. Companies tagged as CleanTech could therefore be software developer or hardware producer, but it could equally be a company that manufactures clean energy generators (like wind turbines), low-to-no emission machinery ("clean" robotics, for example), or even uses advancements in biology to benefit the environment (e.g. artificial trees that capture carbon).

[2] Beauhurst's High Growth firms are defined as having one of the following: Equity fundraising, MBO/MBI, Debt fundraising, Accelerator attendance, 10%/20% scale-up, Academic spinout, Grant received

[3] ClimateBERT is a large language model that is trained on a corpus of climate related text made up of climate-related research paper abstracts, corporate and general news and reports from companies.

2.1 Challenges and limitations

Throughout the project there was a challenge faced in defining and operationalising Net Zero technologies. For example, related terms are often used interchangeably: clean tech, and climate tech, for example, were commonly used interchangeably with Net Zero technologies, and precise definitions are not always clear. In the appendices we have mapped out some classification systems to understand the overlap between these ideas (see Appendix 2). For this report, we will use the terms used by the data source. We will make clear where, for example, a term is used in a broader sense (e.g. clean tech and climate tech often cover more than Net Zero).

The difficulties around identifying what can or cannot be assumed to be a 'green', 'clean' or Net Zero technology leads to a limitation that, across all measures, we assume by applying certain sampling techniques we are capturing technologies which address environmental issues, with a particular focus on GHG emission reductions, however, in many cases the technology will 'potentially' reduce emissions, rather than providing a concrete measure of GHG emissions reduced (see Mealy & Teytelboym, 2022).

Each data source itself has particular limitations. In table 1, we outline the pros and cons of each data source.

Table 1: Overview of Advantages and Disadvantages of Data Sources

Data Source / Approach	Advantages	Disadvantages
Patents **(Nagaoka et al., 2010)**	» Well established measure of innovation with standardised methods of analysis » Structured data that are easily accessed and analysed	» Not all patents are then commercialised. » Not all commercial innovations are patented. » A raw frequency count of patents does not necessarily reflect success in a technology area. » Patents tend to be slow and 'backward' looking as there is a lag in obtaining patents, and as they tell us where innovations have happened rather than suggest where they might happen next
Exports	» Data are widely available » Structured data » Standardised means of using to assess market size	» Represents a snapshot in time » Often does not reflect other factors in competitiveness of product (i.e. price, quality etc)
'Real time' investment data	» Provides time series data » More responsive to updates in investment market	» Less standardised measures » Reliability of data requires more verification. » Sensitive to sample selection » Approach to technology tagging provides indication of technology types rather than distinct technologies » Qualitatively reviewing tags can introduce subjectivity particularly on topics that are hard to operationalise.

3. Patent-based insights

To understand where the UK is competitive in terms of patented technology development in comparison to the global market, Revealed Technological Advantage (RTA) is a useful measure which takes the number of UK patents in a technology class and divides this by the number of global patents in that class. Curran et al (2022) use this measure to demonstrate that the **UK has particular specialisation in tidal stream, offshore wind, carbon capture, utilisation and storage (CCUS) and nuclear technologies.** Their analysis relies on the BEIS clean technologies classification which can be found in Appendix 3 and is based on 2015-2018 patent data.

In our Stage 2 dataset, we found that, even with specific targeting of companies with climate related patent tags, only 25% (n:801) of our sample had been granted a patent. This highlights a key limitation of patent related data analysis, whereby not all innovations and technologies are patented and that the patent process can be slow and favour types of companies. What we can see from our dataset is that industries with experience in patenting (i.e. medical fields) are strongly represented and that the data reflects existing strengths in hydro, wind and automotives – also reflected in our industry analysis. It should be noted our data sample targeted the Y02 and Y04 patents classifications specifically and that these are broad classifications for Climate Change related patents, rather than exclusively Net Zero patent codes hence medical interventions that might be needed to adapt to a new climate are also represented. Within our dataset, the analysis showed a strong alignment between energy patenting and our dataset (see table 2).

Table 2: CPC Patent Classification of 'Real Time' dataset

CPC patent class	Description	N of Patents in the Dataset
Y02A 50/30	Against vector-borne diseases, e.g. mosquito-borne, fly-borne, tick-borne or waterborne diseases whose impact is exacerbated by climate change	47
Y02E 10/72	Wind turbines with rotation axis in wind direction	26
Y02E 60/10	Energy storage using batteries	25
Y02E 10/30	Energy from the sea, e.g. using wave energy or salinity gradient	24
Y02E 10/20	Hydro energy	21
Y02T 10/12	Improving Internal Combustion Engine efficiencies	20
Y02T 10/70	Energy storage systems for electromobility, e.g. batteries	19
Y02W 30/91	Use of waste materials as fillers for mortars or concrete	19
Y02E 50/10	Biofuels, e.g. bio-diesel	18
Y02W 30/62	Plastics recycling; Rubber recycling	18

3.1 Return on investment for clean tech

Martin & Verhoeven (2022) further developed a novel means of understanding the return on investment from government support for innovation which includes private returns, direct and indirect knowledge spillovers from other firms. Their analysis is based on patent technology class and demonstrates that overall investment in clean technologies provides a good return on investment for government, but in particular that **tidal stream and offshore wind energy are likely to generate high levels of economic benefit** from government investment in the UK context. **CCUS, smart systems and building fabrics are also providing high levels of return**, whereas AI demonstrates a high level of patenting, but currently low levels of return based on patent data from 2005-2014 (Curran et al., 2022).

4. Export-based insights

Using Revealed Competitive Advantage (RCA) can help us understand the levels of competitive exporting of particular technologies demonstrating a relative strength when compared to other technologies (or countries). The Product Complexity Index (PCI) is a measure of the relative complexity of a technology (determined by the similarity of the countries that export them competitively – see appendix 4 for a full description of measures) (Andres & Mealy, 2023). Technologies with a high PCI suggest that they are likely to have high spillover effects (Serin & Andres, 2024). Proximity measures the product's similarity to the country's productive capabilities and is correlated with the probability of developing future competitiveness in a product. The analysis below in figure 1 shows groups of technologies that are most competitive in the UK (i.e. have an RCA>1), alongside their PCI, and proximity measure. In general, the UK has a broad range of highly complex products within the technology groups, which have potential to lead to high value when exported, as well as good knowledge spillover effects into other industries. However, the current analysis suggests there is still scope to realise comparative advantage in these highly complex technologies which would require ensuring a connection between innovation support provided, and support for international trade and exporting. This pattern reflects broader technological trends in the UK where we tend to excel at early-stage technological development, but struggle to move towards later stages of the technology readiness levels, and make the jump from start up to scale up.

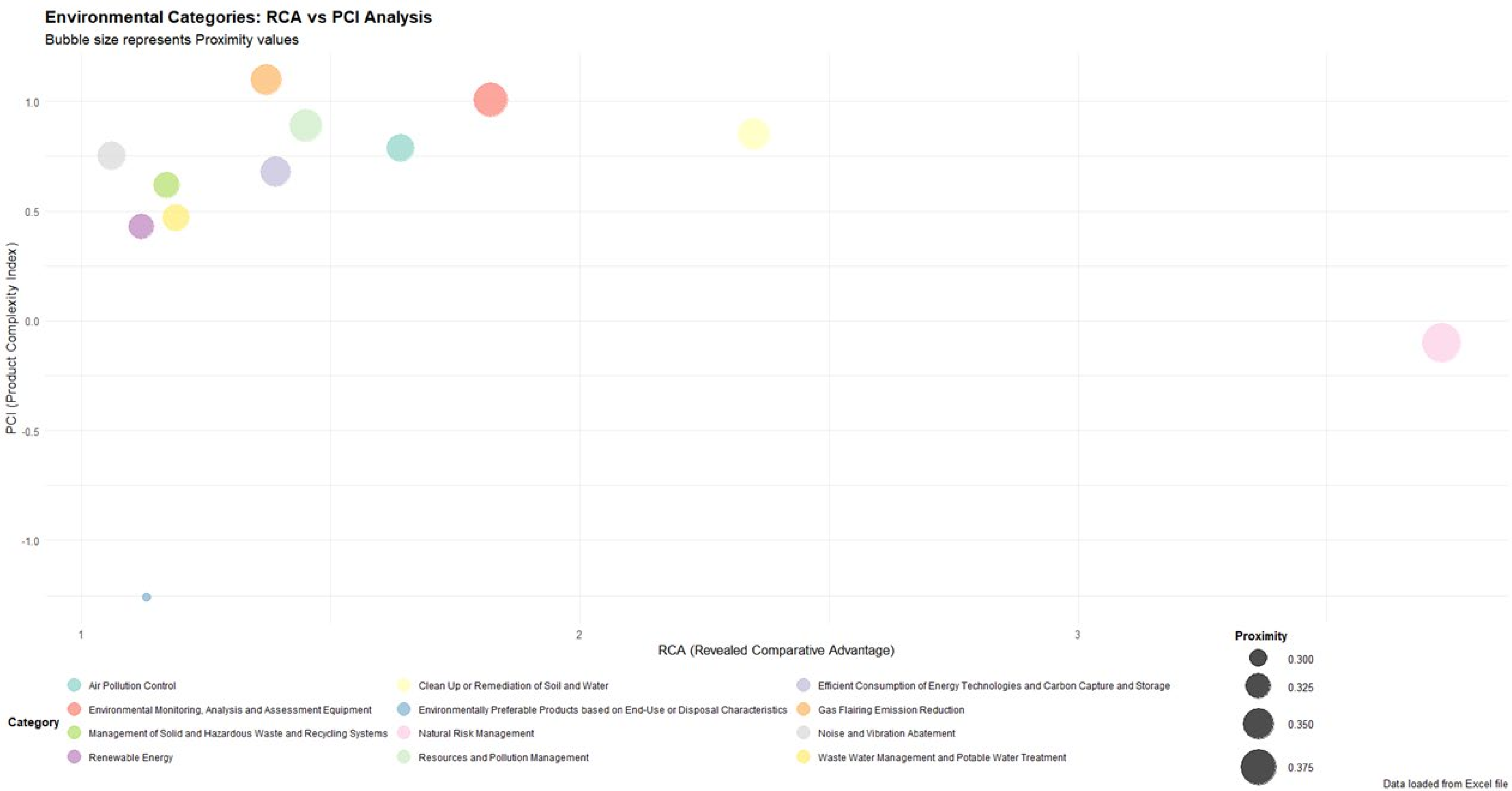

Figure 1: Green Competitiveness: Relative Competitive Advantage (RCA), Product Complexity Index and Proximity averaged over 2019-2023 (Data Source: Andres & Mealy, 2023)

Technology groups that suggest a high level of economic benefit from this analysis include:

- **Gas flaring emissions reduction:** products under this category predominantly relate to furnaces, equipment related to heating and cooling, gas treatments and monitoring/controlling temperature. They are, according to the PCI analysis, highly complex products requiring high levels of specialization. The UK has 3% of the global export market share for these products (compared with Germany 16%, China 15% and USA 12% who are the top three exporters in this category).
- **Environmental monitoring, analysis and assessment:** this category contains a wide range of equipment from thermostats to equipment for chemical analysis and machines for balancing mechanical parts. They are, according to the PCI analysis, highly complex products requiring high levels of specialisation. The UK has 3% of the global export market share for these products (compared with USA 16%, Germany 15% and China 12% who are the top three exporters in this category).
- **Clean up/remediation of soil & water:** products under this category relate to equipment which heats soil, purifies water or other liquids. They have a relatively high RCA in the UK, suggesting that the UK is competitive in exporting these products. The UK has 3% of the global export market share for these products (compared with China 32%, Germany 11% and USA 10% who are the top three exporters in this category).
- **Natural risk management:** this category contains quite a compact set of products related to surveying instruments. These products have a high RCA (suggesting the UK exports these products at a competitive level) and a high proximity (suggesting innovations in this category fit well with the UK's current competencies). The PCI of these products suggest that they are perhaps not as specialized as other categories. The UK is one of the top exporters in the world of these products with 10% of the global exports market, falling behind only USA (23%) and China (12%).
- **Renewable Energy:** products under this category range from products made from renewable energies, to equipment used in generating renewable energy – both specialised and generic. It is a very broad range of products. That the product range is mixed, is perhaps why the PCI is lower than in other more tightly defined categorisations. The UK has 3% of the global exports market with China (22%), Germany (13%) and Japan (9%) being the top exporters in the renewable energies category. The UK's strength in exports seems to have slightly decreased while China's grew (see figure 2). Building support for complex renewable energy technologies to compete on the global scale requires a connection between early-stage support to building an exporting mindset in firms.

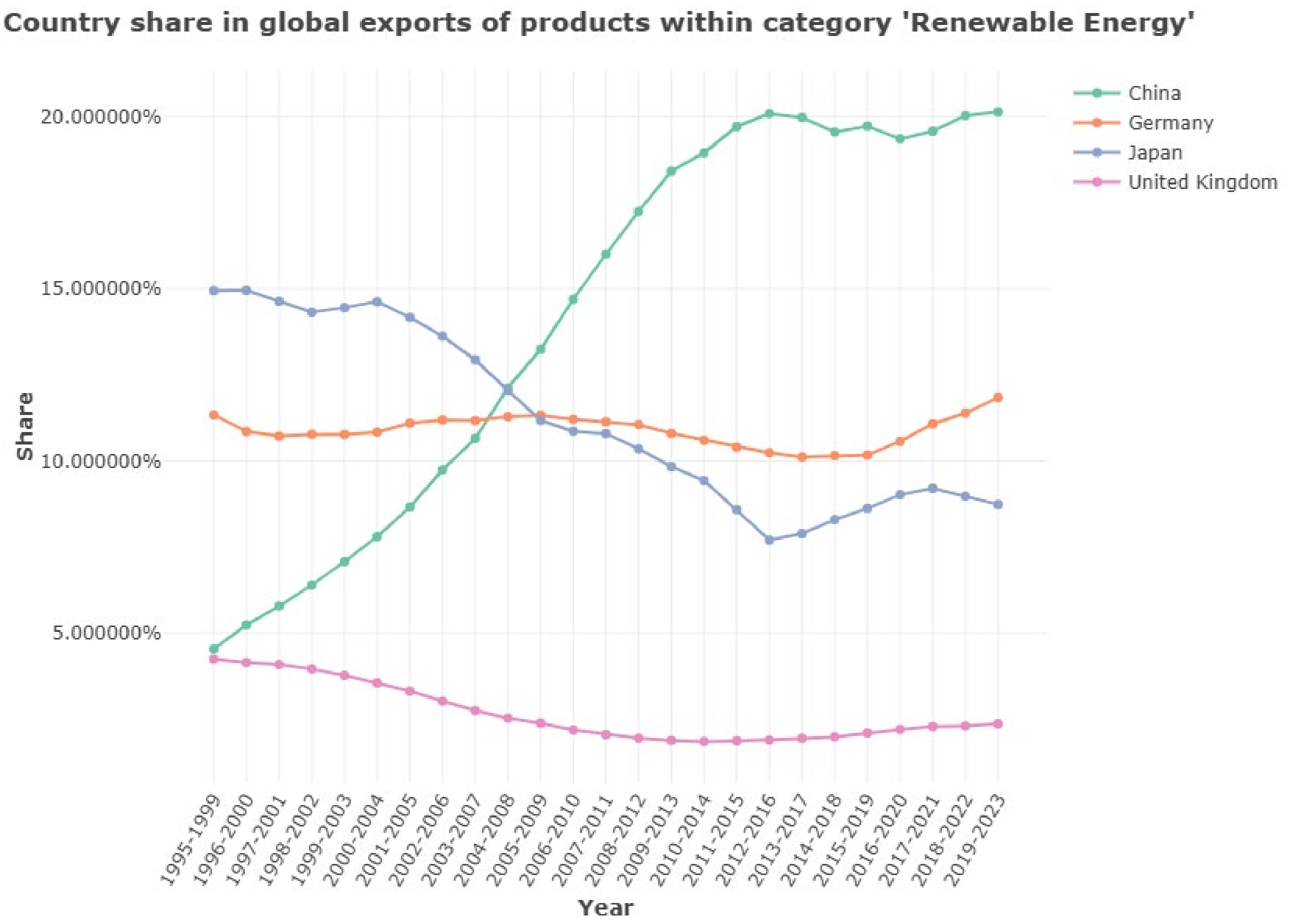

Figure 2: UK, China, Germany and Japan's Export Market Share of Renewable Energy Technologies from 1995-2023 (Source: Andres & Mealy, 2023)

4.1 High Emissions as Opportunities

While the categories above explore current strengths in UK patents and exports of Net Zero technologies, researchers have also explored potential for future strengths from transition away from current high emitters. Brown product categories discussed are based on Andres et al's (2023, p.11) work who composed a list of brown products based on high emitting "products for which global demand is likely to decline as the world decarbonizes" which are "brown in their *use*, rather than production". This leads to the focus on fossil fuels and cattle farming. The Green Transition Outlook (GTO) of the Green Transition Navigator provides data to understand how a 'brown product' (i.e. one that can be considered as highly emitting) relates to a green product (Andres & Mealy, 2023). A higher GTO score would mean that a product can be more easily transitioned to a green project. Figure 3, below, shows that, in general, the opportunity comes from transitioning fossil fuel technologies rather than cattle farming. If the UK is looking for opportunities to make big gains in GHG reductions and maintain economic benefits, transitioning fossil fuels will be key, again suggesting that investment in support for fossil fuel products to be adapted for green energy production is important.

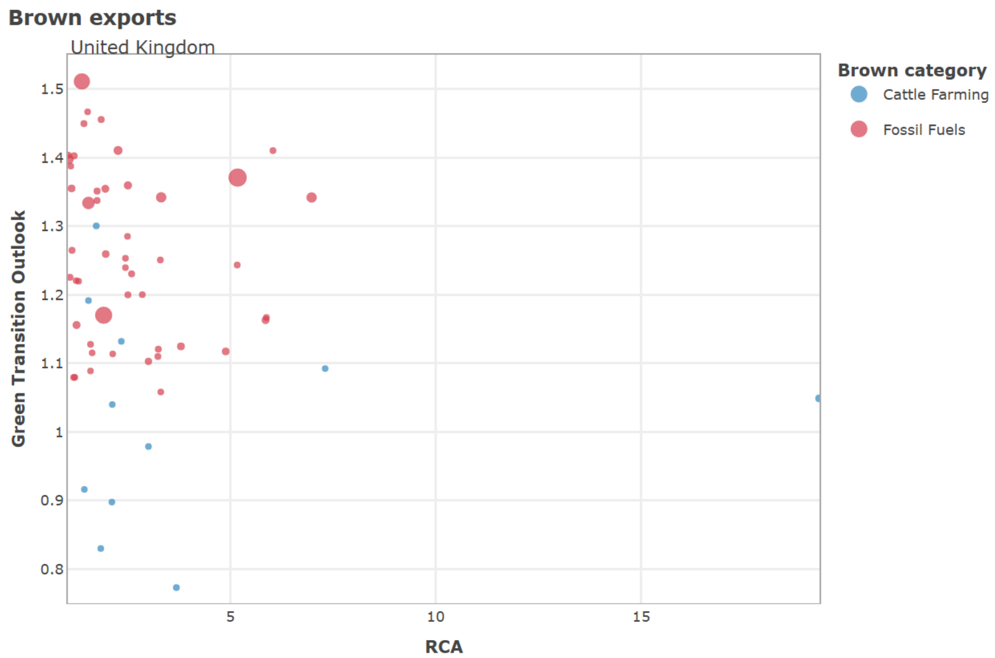

Figure 3: Green Transition Outlook for Brown Product (Andres & Mealy, 2023)

5. ‘Real time’ data insights

The section that follows starts with descriptive statistics on the technologies and industries present within the database of 3,247 firms from Beauhurst followed by more robust statistical analyses of the intersections between technology and industries and the technology groups relationship to sources of funding received by firms in the Net Zero field.

5.1 Technologies

Within our sample, a fifth of the firms were flagged as potentially developing technologies related to **Renewable Energy**, with a further 8% relating to other forms of **Net Zero Energy production (e.g. nuclear, hydrogen, biomass and other non-specific ‘clean’ energy technologies** (see Appendix 6 for Energy tags)**).** The dominance of Net Zero related technology tags is perhaps unsurprising since energy remains a strong focus area to reduce the UK’s GHG emissions. The transport tag is the second largest technology development area and is dominated by electric vehicle developments.

Table 3: Top 10 Technology Groups in our Data Sample

Technology Group	No. of Firms	Percentage of firms (total=2446)
Renewables	499	20%
Transport	247	10%
Energy Storage & Batteries	210	9%
Energy	207	8%
Heating & Cooling	181	7%
Materials & Packaging	80	3%
Software	79	3%
Recycling & Recovery	61	2%
Water (Purification)	49	2%
CCUS & Carbon Reduction	47	2%

We looked at the balance between high growth firms by technology group. Figure 4 shows a ‘long tail’ distribution of firms with most of the high growth firms within a small number of Net Zero technology groups, and that **Renewable Energy** firms have the highest representation of high growth firms within our dataset. However, distance between the number of high growth firms to all firms is also largest within our sample suggesting that although they make up a large component in our sample, there is a need to understand how to move more of the Renewable Energy firms towards high growth if the UK is seeking to maximise economic benefits from Net Zero technologies.

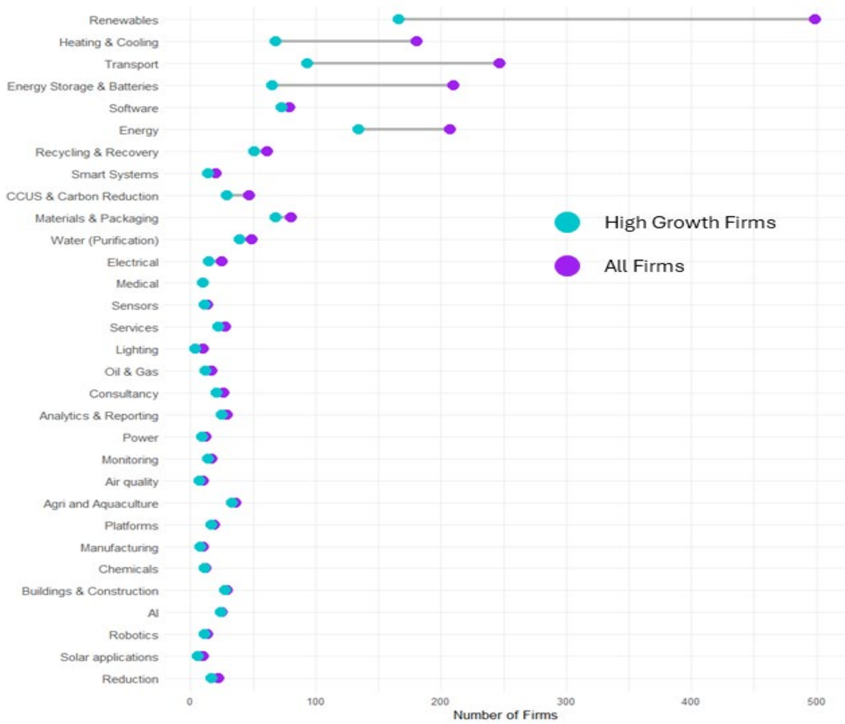

Figure 4: All Firms vs High Growth Firms by Technology Group

5.2 Industries

While technologies in themselves give us a strong idea of where the value is being created in the UK economy from Net Zero technologies, we also explored how industries operating in Net Zero intersected with each other. The Standard Industry Classification (SIC) system is designed to be a universal way of classifying companies to industries; however, it has some key limitations around how companies define themselves, and the levels of nuance available. We therefore compared three approaches to tagging companies in our dataset with industries. We explored the SIC codes, used the BERT large language model to generate tags using the company description, and we compared against the data source's own industry tags (Beauhurst). Of the three options, the Beauhurst tags were most suitable for our analysis as they were more complete and higher level of accuracy. Appendix 5 provides an extract of the industry tags in our data sample.

We then performed an industry space analysis, based on the Beauhurst industry tags, which can give us insight into the potential sources of innovation that might come from unusual collaborations across industries. This analysis of industry space shows opportunities for likely future diversification and innovative capacity (Whittle, 2020; Balland et al., 2019). The connections show the existing capabilities while a lack of connections offer space for diversification or innovation to emerge. Based on the technology space analysis (see Whittle & Kogler, 2019; Whittle, 2020), Figure 5 demonstrates how industries branch out into sectors that are cognitively proximate to each other. This is generated using information on the cooccurrence of Beauhurst industry tags. Industries that are related or share a common core, should be closer together in the industry space than those that do not.

Figure 5 shows some interesting intersections between areas such **Energy and Logistics and Marine where Offshore Wind** plays a key connecting role through to industries related to marine and maritime activities and through logistics to **Automotive and Mobility**. From figure 5 we see three distinct groups of clusters forming; (1) Healthcare & Pharma, Food & Agriculture, and Plastics & Recycling; (2) Energy (with utilities, hospitality, buildings & finance); and (3) Logistics & Marine and Automotive & Aviation. Group 2, Energy, is at the centre of the Net Zero industries connecting multiple industries. The combination of energy and other related industries is more likely to be found in the companies in the UK. On the contrary, the connections between group 1, Healthcare and Pharma, Food & Agriculture, and Plastics & Recycling, and group 3, Logistics and Marine, and Automotive and Aviation, are less likely to be found. The innovative capacity at Net Zero seems to be triggered by energy-related businesses, suggesting that UK investment in energy firms is creating strong connections across industries. An interesting avenue would be to explore the connections between those sectors more distant to each other. For example, Plastics & Recycling with Automotive and Aviation, where there seems to be space for more innovative business to emerge.

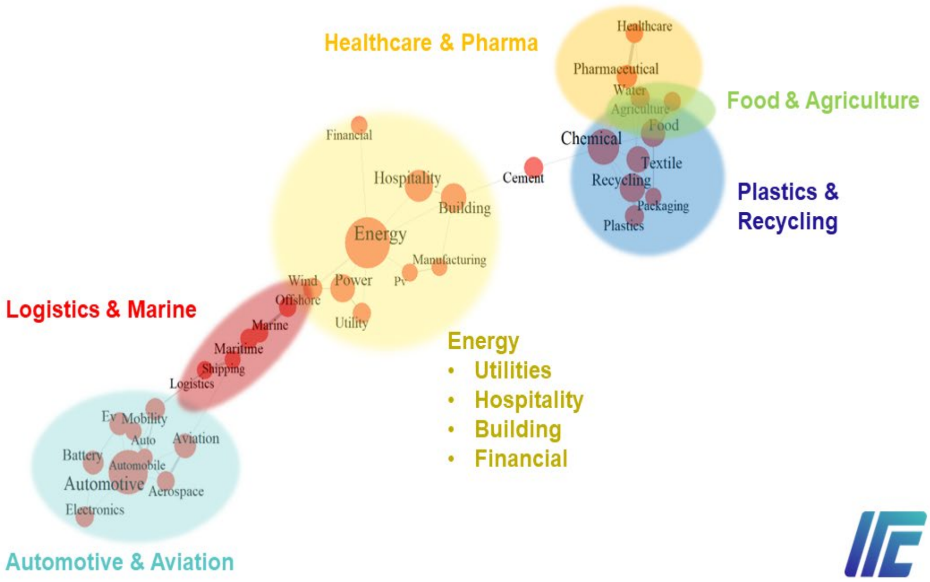

Figure 5: Cluster Analysis of 'Real Time' Data Industries

5.3 Technologies & Intersections with Industries

We performed a series of analyses to understand the penetration of different technologies into key industrial areas. Understanding where technologies are penetrating into diverse ranges of industries can speak to specialisation meaning they can have a higher value as they are scarcer or can suggest where enabling technologies might be adding significant amounts of value to the Net Zero economy.

We took one network of nodes of 22 technologies (those with higher than 10 occurrences on the dataset) and another network of nodes of 33 industries and cross mapped them to each other. This network shows technologies connected to other technologies, based on shared industries (See figure 7). To create the network, we looked at measures of 'closeness' and 'betweenness' centrality. Closeness centrality captures how close a technology (node) is with respect to the other technologies/industries in the network, whereas betweenness centrality measures how many times a node (technology/industry) intermediates among others (i.e. whether a technology is more likely to act as a bridging technology) (see Appendix 7 for the full list of technologies groups and industries by closeness and betweenness). When we actively look for technologies that are likely to bridge the different industries (betweenness centrality) as this allows us to see where technologies might have a larger economic impact than if they remain siloed in a particular domain. Technologies that bridge industries may have diverse applications meaning they may generate higher levels of economic value. **Transport and Energy technologies are strong bridging technologies**, connecting across industries and other technologies meaning they are more likely to penetrate across industries and offer a larger market opportunity. Energy technologies here refer to Net Zero energy technologies that are not renewables but are related to green energy generation (See Appendix 6).

To look further at the relationships between technologies, we used a repeated sampling method (the stochastic method) to calculate the significant connections. Figure 8 shows the resulting network diagram, depicting only statistically significant relationships[4]. **Two clusters appear in this network: (1) Renewables, Heating, Energy, and Energy Storage and Batteries; and (2) Services, Artificial Intelligence, and Analytics. Net Zero Technologies tend to remain specialised in their area**, rather than penetrating a diverse range of industries when we apply a high threshold to understand statistically significant relationships. Supporting firms working on Net Zero technologies in strong siloes to understand the potential to open technological advances for other industrial applications, so that innovations diffuse across to new applications would strengthen the economic benefits of investment in Net Zero technologies. Enabling technologies such as Software, AI and Digital Platforms already have very diverse applications which should cut across industry boundaries, meaning there is scope to support the diffusion of these innovations in firms working on other Net Zero technologies.

[4] We used the backbone package for R (v2.1.4; Neal, 2022) to extract the unweighted backbone of the weighted projection of an unweighted bipartite network containing 22 techs and 33 industries. An edge was retained in the backbone if its weight was statistically significant (alpha = 0.05) using the fixed degree sequence model (FDSM; Neal, 2014), where p-values were estimated from 80297 Monte Carlo trials. This reduced the number of edges by 95.7%, and reduced the number of connected nodes by 68.2%

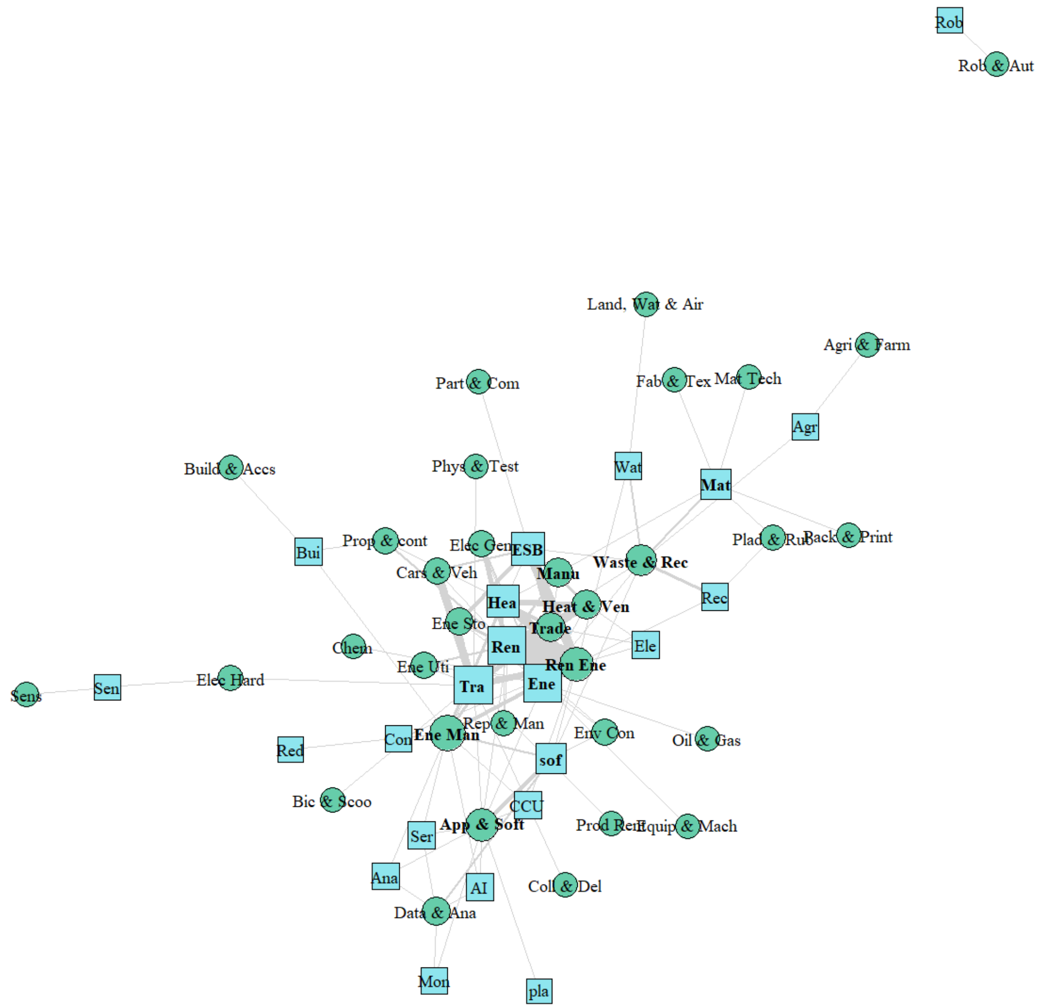

Figure 7: Network Diagram of Technologies and Industries

Type	Code	Label
Industry	Agri & Farm	Agriculture, land farming and forestry
Industry	App & Soft	Application Software
Industry	Bic & Scoo	Bicycles and scooters
Industry	Build & Accs	Building materials, tools and accessories
Industry	Cars & Veh	Cars, motorcycles and other road vehicles
Industry	Chem	Chemicals
Industry	Coll & Del	Collection and delivery
Industry	Data & Ana	Data provision and analysis
Industry	Elec Gen	Electricity generation
Industry	Elec Hard	Electronics hardware
Industry	Ene Man	Energy management and reduction
Industry	Ene Sto	Energy storage
Industry	Ene Uti	Energy utilities
Industry	Env Con	Environmental consultancy
Industry	Fab & Tex	Fabrics and textiles
Industry	Heat & Ven	Heating, ventilation, air conditioning and mechanical and electrical systems
Industry	Equip & Mach	Heavy equipment and machinery
Industry	Land, Wat & Air	Land, water and air management
Industry	Manu	Manufacturing
Industry	Mat Tech	Materials technology
Industry	Oil & Gas	Oil and gas
Industry	Pack & Print	Packaging and printing
Industry	Part & Com	Parts and components
Industry	Phys & Test	Physical product design, testing and quality assurance
Industry	Plad & Rub	Plastics and rubber
Industry	Prod Rent	Product rental and hire
Industry	Prop & cont	Property development and construction
Industry	Ren Ene	Renewable energy
Industry	Rep & Man	Repair, maintenance and servicing
Industry	Rob & Aut	Robots and automation
Industry	Sens	Sensors
Industry	Trade	Tradespeople and trade services
Industry	Waste & Rec	Waste management and recycling
Tech	Agr	Agri and Aquaculture
Tech	AI	AI
Tech	Ana	Analytics & Reporting
Tech	CCU	CCUS & Carbon Reduction
Tech	Ene	Energy
Tech	Mon	Monitoring
Tech	pla	platforms
Tech	Ren	Renewables
Tech	Ser	Services
Tech	sof	software
Tech	Tra	Transport
Tech	Bui	Buildings & Construction
Tech	ESB	Energy Storage & Batteries
Tech	Hea	Heating & Cooling
Tech	Sen	Sensors
Tech	Con	Consultancy
Tech	Red	Reduction
Tech	Mat	Materials & Packaging
Tech	Ele	Electrical
Tech	Wat	Water Purification
Tech	Rec	Recycling & Recovery
Tech	Rob	Robotics

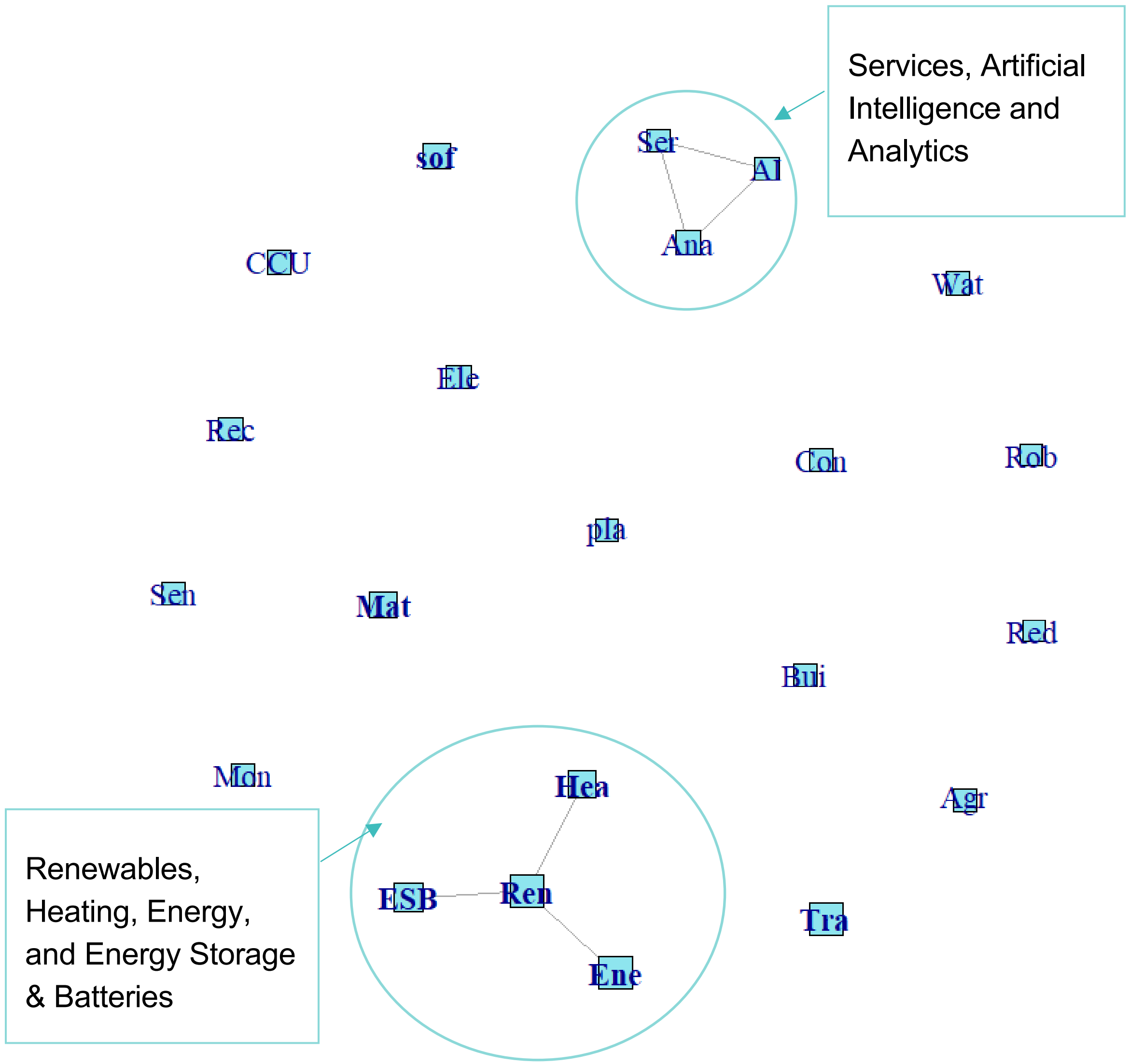

Figure 8: Network Diagram of Statistically Significant Clusters of Technologies & Industries

Type	Code	Label
Industry	Agri & Farm	Agriculture, land farming and forestry
Industry	App & Soft	Application Software
Industry	Bic & Scoo	Bicycles and scooters
Industry	Build & Accs	Building materials, tools and accessories
Industry	Cars & Veh	Cars, motorcycles and other road vehicles
Industry	Chem	Chemicals
Industry	Coll & Del	Collection and delivery
Industry	Data & Ana	Data provision and analysis
Industry	Elec Gen	Electricity generation
Industry	Elec Hard	Electronics hardware
Industry	Ene Man	Energy management and reduction
Industry	Ene Sto	Energy storage
Industry	Ene Uti	Energy utilities
Industry	Env Con	Environmental consultancy
Industry	Fab & Tex	Fabrics and textiles
Industry	Heat & Ven	Heating, ventilation, air conditioning and mechanical and electrical systems
Industry	Equip & Mach	Heavy equipment and machinery
Industry	Land, Wat & Air	Land, water and air management
Industry	Manu	Manufacturing
Industry	Mat Tech	Materials technology
Industry	Oil & Gas	Oil and gas
Industry	Pack & Print	Packaging and printing
Industry	Part & Com	Parts and components
Industry	Phys & Test	Physical product design, testing and quality assurance
Industry	Plad & Rub	Plastics and rubber
Industry	Prod Rent	Product rental and hire
Industry	Prop & cont	Property development and construction
Industry	Ren Ene	Renewable energy
Industry	Rep & Man	Repair, maintenance and servicing
Industry	Rob & Aut	Robots and automation
Industry	Sens	Sensors
Industry	Trade	Tradespeople and trade services
Industry	Waste & Rec	Waste management and recycling
Tech	Agr	Agri and Aquaculture
Tech	AI	AI
Tech	Ana	Analytics & Reporting
Tech	CCU	CCUS & Carbon Reduction
Tech	Ene	Energy
Tech	Mon	Monitoring
Tech	pla	platforms
Tech	Ren	Renewables
Tech	Ser	Services
Tech	sof	software
Tech	Tra	Transport
Tech	Bui	Buildings & Construction
Tech	ESB	Energy Storage & Batteries
Tech	Hea	Heating & Cooling
Tech	Sen	Sensors
Tech	Con	Consultancy
Tech	Red	Reduction
Tech	Mat	Materials & Packaging
Tech	Ele	Electrical
Tech	Wat	Water Purification
Tech	Rec	Recycling & Recovery
Tech	Rob	Robotics

5.4 Technologies & Funding

We sought to understand the relationship between different types of technology and different types of funding into firms indicating that they are using those technologies. Within our dataset we had information on the number and size of grant and equity funding a company has received. Public investment in technology development can be seen as a means to leverage and encourage private investment, however, it also runs the risk of 'crowding out private investment (i.e. where public investment reduces private investment). Equally, the equity market can demonstrate technology areas where public investment can provide complimentary areas of investment (e.g. areas where public investment could fund patient capital where private investment might seek shorter term returns). Figure 9 shows the amount of funding received by firms associated with a particular technology tag, split by amount of equity finance, and grants. From this chart we see that **Energy, Energy Storage and Batteries and Transport received the highest level of equity investment, followed by Renewables, and CCUS & Carbon Reduction**. Whereas when we analyse the grant funding received by technology groupings, the highest level was received by the **Renewables technology group, followed by Energy technologies and Transport technologies**.

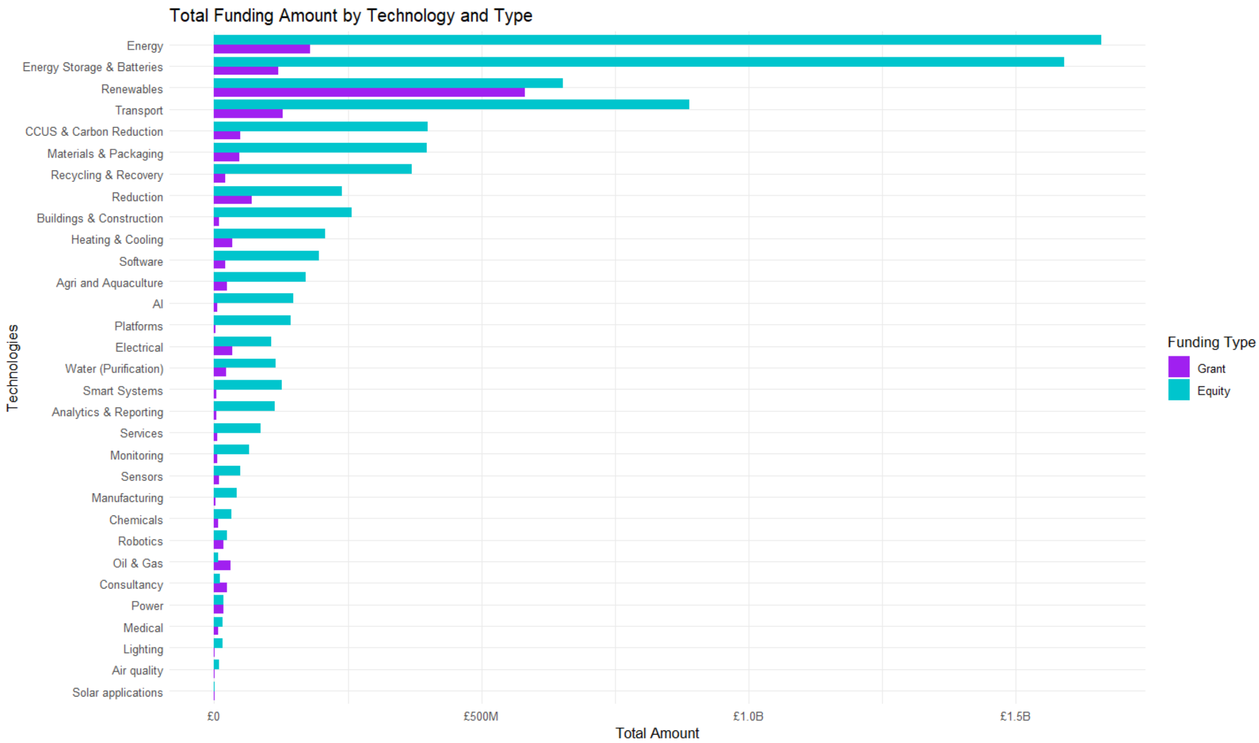

Figure 9: Technology Groups by Amount of Funding per Funding Type

We aggregated these figures by technology group (focusing on those who had 10 or more associated firms) and tested with regressions the technology groups that were more likely to receive different types of funding than the overall sample of firms. The regressions indicated that a companies' use of a particular Net Zero technology (as indicated in their company descriptions) was unlikely to improve the chances of receiving either grant or equity funding. In many cases, we found technologies to have a negative relationship with funding types, suggesting that the use of these technologies was less likely to receive funding. There are three exceptions to this pattern:

(1) **Materials and Packaging** technologies have a positive significant relationship to the ability to get equity (Table 4)
(2) **Digital Platforms** have a positive significant relationship to receiving equity investment
(3) **Software** has a positive significant relationship with receiving equity investment

Software, Digital Platforms, and to a lesser extent, Materials and Packaging, represent more cross cutting technologies and all three technology types encompass both highly novel developments and technologies that are more mature in terms of their technology readiness levels, perhaps suggesting investors see a stronger case for investment.

Patenting, being a spinout, attending spinout events and participating in accelerators all have a positive statistically significant relationship with the funding metrics proving to be better means of predicting funding than the majority of identified Net Zero technology groups. Activities such as patenting, being a spinout, attending spinout events and participation in accelerators act as signals of credibility to investors. To maximise the potential of Net Zero technologies, and build on what the UK is already good at, targeting Net Zero specific programmes for spinout and accelerators could prove fruitful, particularly if they focus on means of patenting technologies, and export readiness.

Table 4: Logistic Regression Analysis of Technologies on the Probability of Receiving Funding

Variables associated with the probability of receiving Equity or Grant funding at least one time[5]	Equity (yes/no)	Grant (yes/no)
Patents (Yes = 1)	0.321****	0.215*
N of Employees	-0.002**	0.001*
MBO/MBI (Yes = 1)	-0.127	1.02
Is a Spinout (Yes = 1)	1.601	1.189
Accelerator Attendances (Yes = 1)	0.795****	1.862****
Spinout Events Attendances (Yes = 1)	0.880**	2.152****
Agri and Aquaculture	-0.643+	0.688
AI	0.577	-0.016
Air quality	-0.149	0.689
Analytics & Reporting	0.243	-0.196
Buildings & Construction	-0.425	0.106
CCUS & Carbon Reduction	0.09	-0.103
Chemicals	-0.504	1.025
Consultancy	-0.376	-0.963+
Electrical	-1.817**	-0.862*
Energy	-0.454*	0.182
Energy Storage & Batteries	-0.670***	-0.427*
Heating & Cooling	-1.029****	-0.604**
Lighting	-0.74	-0.197

[5] The estimators of technologies denote the difference in log-odds between firms belonging or not in this category. For example, *Materials & Packaging* firms have an estimator of 0.492 in the Equity model, which means that the odds of *Materials & Packaging* firms are $e^{0.492}$= 1.6355 higher of receiving an equity than *non-Materials & Packaging* firms.
Additionally, we note that correlation analysis did not diagnose any multicollinearity problems.

Variables associated with the probability of receiving Equity or Grant funding at least one time[5]	**Equity (yes/no)**	**Grant (yes/no)**
Manufacturing	-0.625	0.747
Materials & Packaging	0.492+	0.622*
Medical	-0.672	1.921
Monitoring	0.114	0.189
Oil & Gas	-0.557	-0.007
Digital Platforms	1.735*	-0.719+
Power	0.498	0.18
Recycling & Recovery	0.155	0.332
Reduction	0.019	-0.852
Renewables	-1.249****	-0.930****
Robotics	0.485	0.984
Sensors	0.797	0.756
Services	0.08	-0.427
Smart Systems	-0.094	-0.592
Software	0.972**	-0.569
Solar applications	-0.335	0.056
Transport	-0.546**	-0.698***
Water (Purification)	0.237	0.399
N = 1898		*Negative*
+ p<0.10, * p<0.05, ** p<0.01, *** p<0.001, **** p<0.0001		*Positive*

Table 5: Linear Regression Analysis of Technologies on the Amount of Funding Received (in millions of pounds)

Variables associated with the amount of Equity or Grant funding received [6]	Equity – Amount (£mil)	Grant – Amount (£mil)
Patents (Yes = 1)	1.020*	0.179****
N of Employees	0.001	0
MBO/MBI (Yes = 1)	-3.492	0.859
Is a Spinout (Yes = 1)	29.656+	1.271
Accelerator Attendances (Yes = 1)	0.146	0.226
Spinout Events Attendances (Yes = 1)	4.611*	0.637*
Agri and Aquaculture	-0.983	-0.356
AI	3.309	-0.658*
Air quality	-4.838***	-0.848***
Analytics & Reporting	-1.685	-0.753***
Buildings & Construction	5.487	-0.626+
CCUS & Carbon Reduction	6.259	-0.244
Chemicals	-4.950*	-0.545
Consultancy	-6.155***	0.199
Electrical	-3.885*	0.28
Energy	3.035	-0.086
Energy Storage & Batteries	7.38	-0.659
Heating & Cooling	-4.208*	-0.995
Lighting	-1.067	-0.687+

[6] In this linear regression analysis, the estimators of technologies denote the change in the expected funding between firms belonging or not in this category. For example, *Air quality* firms have an estimator of -4.838 in the Equity model, which means that *Air quality* firms are associated with a decrease of £4.838 million in expected Equity funding compared to *non-Air quality* firms.
In addition, we note that the correlation analysis did not diagnose any multicollinearity problems.

Variables associated with the amount of Equity or Grant funding received [6]	Equity – Amount (£mil)	Grant – Amount (£mil)
Manufacturing	-0.372	-0.723*
Materials & Packaging	-2.089	-0.528*
Medical	-6.392****	-0.533
Monitoring	-2.055	-0.662*
Oil & Gas	-5.264***	-0.465*
Digital Platforms	2.853	-0.672**
Power	-6.253**	0.819
Recycling & Recovery	1.25	-0.521*
Reduction	-8.954*	0.065
Renewables	-5.344+	0.997
Robotics	-3.951**	0.571
Sensors	-3.224+	-0.609
Services	-2.384	-0.806**
Smart Systems	-0.036	-0.779*
Software	-2.946*	-0.593**
Solar applications	-6.597*	-0.521**
Transport	-1.505	-0.304
Water (Purification)	-3.993**	-0.557*
N = 1898		*Negative*
+ p<0.10, * p<0.05, ** p<0.01, *** p<0.001, **** p<0.0001		*Positive*

6. So What?

There is no single way of understanding where the UK's strengths are in terms of economic benefit from Net Zero technologies. In table 5 we compare the technology groups perceived by these measures as having key strengths. From this table it is clear that the different measures highlight the diverse technological strengths in the UK Net Zero market. While this diversity is clearly a strength, particularly when it comes to highly specialised technologies, it can be challenging to build in support for the wide range of technology groups across the full Net Zero portfolio.

While from table 5, we can see that there are distinct groups of technologies that are considered key strengths for the UK according to their individual measures, there are some broader themes that appear to recognise strengths overall in the UK Net Zero technology market. Energy technologies, from tidal stream, to nuclear and renewables (in particular offshore wind) demonstrate strengths across the board, as areas with competitive advantages in patents, high levels of the export market and linking technologies that are crossing over industry boundaries. There is, however, a clear clustering of activities with strengths of connection between Renewables, Heating, Energy, and Energy Storage & Batteries, which is to be expected.

Similarly, strengths in environmental monitoring, analysis and assessment are identified as a core strength of the UK in terms of exports and could be connected to strengths in Smart Systems as a competitive patentable area that is expected to provide a high level of return on investment. Strengths in equity investment in Software and Digital Platforms could be related to the need for these technologies to facilitate monitoring, analysis and assessment through activities such as emissions tracking and energy efficiency monitoring. While we see that market penetration of generalist technologies such as AI appears low, there is a cluster of activities around Services, Artificial Intelligence and Analytics that might support the idea that AI is beginning to penetrate the Net Zero market through monitoring and tracking. Funding AI as a means of addressing Net Zero challenges could be considered controversial, as CO2 emissions from data centres are concerning.

Table 5: Summary of Technology Groups Demonstrating Strengths According to Different Measures

Data	Technology	Insight	Measure Suggesting Strength	Limitations
Strong technology based on patent data	Tidal Stream	Tidal Stream technologies are an area of international strength in patented technologies for the UK; they are flagged as likely to give a good return on public investment	Revealed Technological Advantage (RTA) Potential Return on Investment	• Not all patents are then commercialised • Not all commercial innovations are patented • A raw frequency count of patents does not necessary reflect success in a technology area • Patents tend to be slow and 'backward' looking as there is a lag in obtaining patents, and as they tell us where innovations have happened rather than suggest where they might happen next
Strong technology based on patent data	Offshore Wind	Offshore Wind technologies are an area of international strength in patented technologies for the UK; they are flagged as likely to give a good return on public investment	Revealed Technological Advantage (RTA) Potential Return on Investment	• Not all patents are then commercialised • Not all commercial innovations are patented • A raw frequency count of patents does not necessary reflect success in a technology area • Patents tend to be slow and 'backward' looking as there is a lag in obtaining patents, and as they tell us where innovations have happened rather than suggest where they might happen next
Strong technology based on patent data	Carbon Capture, Utilisation and Storage (CCUS)	CCUS technologies are an area of international strength in patented technologies for the UK, they are flagged as likely to give a good return on public investment	Revealed Technological Advantage (RTA) Potential Return on Investment	• Not all patents are then commercialised • Not all commercial innovations are patented • A raw frequency count of patents does not necessary reflect success in a technology area • Patents tend to be slow and 'backward' looking as there is a lag in obtaining patents, and as they tell us where innovations have happened rather than suggest where they might happen next
Strong technology based on patent data	Nuclear technologies	Nuclear technologies are an area of international strength in patented technologies for the UK	Revealed Technological Advantage (RTA)	• Not all patents are then commercialised • Not all commercial innovations are patented • A raw frequency count of patents does not necessary reflect success in a technology area • Patents tend to be slow and 'backward' looking as there is a lag in obtaining patents, and as they tell us where innovations have happened rather than suggest where they might happen next
Strong technology based on patent data	Smart systems	Smart systems are flagged as likely to give a good return on public investment	Potential Return on Investment	• Not all patents are then commercialised • Not all commercial innovations are patented • A raw frequency count of patents does not necessary reflect success in a technology area • Patents tend to be slow and 'backward' looking as there is a lag in obtaining patents, and as they tell us where innovations have happened rather than suggest where they might happen next
Strong technology based on patent data	Building fabrics	Building fabrics are flagged as likely to give a good return on public investment	Potential Return on Investment	• Not all patents are then commercialised • Not all commercial innovations are patented • A raw frequency count of patents does not necessary reflect success in a technology area • Patents tend to be slow and 'backward' looking as there is a lag in obtaining patents, and as they tell us where innovations have happened rather than suggest where they might happen next
Strong technology	Clean up/remediation of soil & water	Clean up/remediation of soil & water demonstrates a strong market share of exports on the international market	Relative Competitive Advantage (RCA)	» Represents a snapshot in time

Data	Technology	Insight	Measure Suggesting Strength	Limitations
groups based on exports	Environmental monitoring, analysis and assessment	Environmental monitoring, analysis and assessment shows strengths in their complexity making them strong for the export market	Product Complexity Index (PCI)	» Often doesn't reflect other factors in competitiveness of product (i.e. price, quality etc)
	Natural risk management	Natural risk management technologies demonstrate a strong market share of exports on the international market, and are well aligned with the UK's current capabilities	Relative Competitive Advantage (RCA) & Proximity	
	Gas flaring emissions reduction	Gas flaring emission reduction technologies show strengths in their complexity making them strong for the export market	Product Complexity Index (PCI)	
Strong technology groups based on 'Real Time' Data	Transport	Transport technologies act as a bridging mechanism between different industry groups.	Betweenness	» Less standardised measures » Reliability of data requires more verification » Sensitive to sample selection » Approach to technology tagging provides indication of technology types rather than distinct technologies » Qualitatively reviewing tags can introduce subjectivity particularly on topics which are hard to operationalise
	Energy	Energy technologies act as a bridging mechanism between different industry groups.	Betweenness	
	Materials & Packaging	Materials & Packaging technologies are more likely to attract equity investment in Net Zero firms.	Equity investment received	
	Digital platforms	Digital platform technologies are more likely to attract equity investment in Net Zero firms	Equity investment received	
	Software	Software technologies are more likely to attract equity investment in Net Zero firms.	Equity investment Received	

From this approach we can apply different lenses to the question: “What is the UK good at in terms of Net Zero technologies that contribute to the economy?”. By combining a series of different data sources and analyses it is possible to understand the nuances of what ‘good’ might mean in this context. ‘Good’ in terms of economic outcomes of Net Zero technologies can be measured based on patents, exports, penetration into diverse industries and investment into technologies by equity and grant funding. While applying these different lenses highlights different technology groups that demonstrate strengths in the UK, each strength is predicated on a particular perception of ‘success’. Furthermore, the different ways of categorising technologies create difficulties in mapping the successes of Net Zero technologies. While each measure has implications for what good looks like, it is important to remember they all are indicators of innovative activities.

That the ‘real time’ data and the data related to patents do not demonstrate a significant crossover is perhaps unsurprising, since the ‘real time’ data reflects a broader selection of what Net Zero (and related clean tech) companies are likely to be active in beyond technologies that they themselves are patenting. Similarly, when it comes to exports, the ‘real time’ dataset can capture activities that are not yet at the stage of exporting, or that are focussed on UK internal markets.

Overall, our findings suggest that energy remains a core source of technology development within the Net Zero landscape. Funding energy technologies which are existing areas of strength within Innovate UK, is likely to lead to economic benefits. However, taking a deeper dive looking at particular technology tags within the Energy and Renewable technology groups could create a deeper understanding of what particular technologies are driving the figures on market penetration for example and whether all of these technologies are currently negatively associated with funding meaning that they are less likely to get funding, or if particular energy technologies buck that trend. Understanding which technologies within a technology group might receive equity or grant funding can act as an indicator of where the market might expect to see good economic returns from the technology.

While we have outlined the different potential means of answering the question of what technologies is the UK ‘good’ at in terms of Net Zero, the broader idea of what Innovate UK might be able to influence through its work could take a different angle. Firstly, as we saw, there is limited diffusion of technologies beyond their direct industry applications: encouraging means of broadening market penetration could be a means of opening doors to bigger markets and thus creating a more attractive proposition to increase the equity investment into Net Zero technologies which from our statistical analysis appears limited. While energy and transport provide bridging technologies that connect different technology & industry relationships, other technological developments such as AI seem less well integrated across Net Zero industries. Supporting adoption and diffusion of enabling technologies could escalate our abilities to assess emissions and provide more targeted action while reaping the economic benefits of complex technologies.

Since participating in activities such as patenting, accelerators and spinout events signalled more credibility to investors, there could be scope to increase capacity at existing Net Zero accelerators or target spinout programmes and events related to Net Zero technologies, and building support programmes to increase patenting and a focus on exporting could also build on the UK's relatively complex portfolio of Net Zero technologies

Finally, there are some future research steps that could strengthen our findings: firstly to explore the relationship between grants and equity funding in Net Zero firms to better understand crowding out vs crowding in effects, secondly to look at the effect on turnover of use of particular technologies (as defined by mentioning them in a company description), thirdly to deepen our analysis into unusual combinations (or outliers) in the industry space and technology cluster analysis, fourthly, to take a deeper dive into Energy to more clearly unpack the different economic benefits of particular technologies and finally to breakdown technologies by their technology readiness levels to understand potentially which technologies could benefit from what support at different stages of their development.

References

Andres, P and Mealy, P (2023) *Green Transition Navigator*. Retrieved from www.green-transition-navigator.org

Balland, P. A., Boschma, R., Crespo, J., & Rigby, D. (2019). Smart specialization policy in the European Union: Relatedness, knowledge complexity and regional diversification. Regional Studies, 53(9), 1252–1268.

Curran, B., Martin, R., Muller, S., Nguyen-Tien, V., Oliveira-Cunha, J., Serin, E., Shah, A., Valero, A., & Verhoeven, D. (2022). Growing clean: Identifying and investing in sustainable growth opportunities across the UK, *The Resolution Foundation*, https://economy2030.resolutionfoundation.org/wp-content/uploads/2022/05/Growing_clean_report.pdf

CBI (2025) *The Future is Green: The economic opportunities brought by the UK's net zero economy*. Available: https://www.cbi.org.uk/media/owxdidg1/cbi-economics-eciu-the-future-is-green-report-2025.pdf

EPO 2021. *Updates on YO2 and Y04S* https://www.epo.org/en/news-events/in-focus/classification/classification/updatesYO2andY04S

Innovate UK, (2022). *Innovate UK strategic delivery plan 2022 to 2025*. Available: https://www.ukri.org/publications/innovate-uk-strategic-delivery-plan/innovate-uk-strategic-delivery-plan-2022-to-2025/

Martin, R & Verhoeven, D. 2022. *Knowledge Spillovers from Clean and Emerging Technologies in the UK* https://cep.lse.ac.uk/pubs/download/dp1834.pdf

Mealy, P., & Teytelboym, A. (2022). Economic complexity and the green economy. *Research Policy*, 51(8), 103948.

Nagaoka, S., Motohashi, K., & Goto, A. (2010). Patent statistics as an innovation indicator. In *Handbook of the Economics of Innovation* (Vol. 2, pp. 1083-1127). North-Holland.

Neal, Z. P. (2022). backbone: An R Package to Extract Network Backbones. PLOS ONE, 17, e0269137. https://doi.org/10.1371/journal.pone.0269137

Neal, Z. P. (2014). The backbone of bipartite projections: Inferring relationships from co-authorship, co-sponsorship, co-attendance and other co-behaviors. Social Networks, 39, 84-97. https://doi.org/10.1016/j.socnet.2014.06.001

Serin, E., & Andres, P. (2024). Harnessing the UK's strengths for green growth https://www.lse.ac.uk/granthaminstitute/news/harnessing-the-uks-strengths-for-green-growth/

Webersinke, N., Kraus, M., Bingler, J., & Leippold, M. (2022). *ClimateBERT: A pretrained language model for climate-related text*. In *Proceedings of AAAI 2022 Fall Symposium: The Role of AI in Responding to Climate Challenges*. https://doi.org/10.48550/arXiv.2212.13631

Whittle, A. (2020). Operationalizing the knowledge space: theory, methods and insights for Smart Specialisation, Regional Studies, Regional Science, 7:1, 27-34, DOI: 10.1080/21681376.2019.1703795

Whittle, A., & Kogler, D. (2019). Related to what? Reviewing the literature on technological relatedness: Where we are now and where can we go? Papers in Regional Science, 1–17. doi:10.1111/pirs.12481.

Appendix 1: European Patent Office Climate Change Patent Codes

Y02 and Y04S are patent data codes created by the European Patent Office to aid in the searching and finding of climate change mitigation technologies. YO2 covers:

- Y02A – Adaption to climate change
- Y02B – Buildings
- Y02C – Capture and storage of GHG
- Y02D – ITC aiming at the reduction of own energy use
- Y02E – Production, distribution and transport of energy
- Y02P – Industry & agriculture
- Y02T – Transportation
- Y02W – Waste and Wastewater
- YO4S focuses on smart grid technologies

(EPO, 2021)

Appendix 2 Mapping Tech/Industry Categorisations

Growing Clean Report Classification	TDC RTICS subsectors From Growing Clean Report	Patent	SIC description	Low Carbon Economy Categories
Agriculture and forestry	CleanTech: Agriculture, Forestry and Biodiversity; Net Zero: Agritech	Y02P (Industry and agriculture)	Products of agriculture, hunting and related services; Products of forestry, logging and related services; Land use, land use change and forestry (LULUCF)	
Circular economy/waste	Green Economy: Reduce, Reuse, Recycle and Repair; Net Zero: Diversion of Biodegradable Waste from Landfill; Net Zero: Waste Management and Recycling	Y02W (Waste and wastewater)	Waste collection, treatment and disposal services; materials recovery services; Remediation services and other waste management services	
Climate adaptation	Green Economy: Climate Adaptation	Y02A (Adaptation to climate change)		
Consultancy and services	Green Economy: Climate Change Strategy Research Monitoring and Planning; Net Zero: Low Carbon Consultancy, Advisory and Offsetting Services		Computer programming, consultancy and related services; Information services; Services of head offices; management consulting services	13 Low carbon consultancy, advisory and offsetting services
Demand side management and digit	Artificial Intelligence: GreenTech; Energy Management: AI and IoT; Energy Management: Energy Management Systems; Energy Management: Smart Meter; Internet of Things (IoT): Energy Management; Internet of Things (IoT): Smart Buildings; Internet of Things (IoT): Smart Cities and Transport; Net Zero:	Y04S (Smart grids)		12 Energy monitoring, saving and control systems

Growing Clean Report Classification	TDC RTICS subsectors From Growing Clean Report	Patent	SIC description	Low Carbon Economy Categories
	Renewable Energy Planning Database			
Energy storage	Energy Storage: Batteries; Energy Storage: Hydrogen; Energy Storage: Mechanical; Energy Storage: Thermal; Energy Storage: Uninterruptible power supply; Li-ion battery supply chain: Battery assembly; Li-ion battery supply chain: Battery cells; Li-ion battery supply chain: Material suppliers; Net Zero: Energy Storage	Y02A (Adaptation to climate change)	Electrical equipment	17 Fuel cells and energy storage systems
Environmental monitoring and pollution	CleanTech: Environmental Protection and Monitoring; Green Economy: Reducing Localised Pollution; Net Zero: Pollution Control and Mitigation; Sensors: Environmental Monitoring	Y02P (Industry and agriculture) Y02B (Buildings)		12 Energy monitoring, saving and control systems
Grid and infrastructure	Energy Management: Smart Grid; Green Economy: Green and Blue Infrastructure; Net Zero: Grid	Y04S (Smart grids)		12 Energy monitoring, saving and control systems
Industrial decarbonisation and carbon capture	Green Economy: Industrial Decarbonisation, Hydrogen and Carbon Capture; Net Zero: Carbon Capture	Y02C (Capture and storage of greenhouse gases)		15 Carbon capture and storage

Growing Clean Report Classification	TDC RTICS subsectors From Growing Clean Report	Patent	SIC description	Low Carbon Economy Categories
Low-carbon energy generation	Energy Generation: Bioenergy; Energy Generation: Hydrogen; Energy Generation: Hydropower; Energy Generation: Nuclear; Energy Generation: Renewable Thermal; Energy Generation: Solar; Energy Generation: Wind; Green Economy: Power; Net Zero: Energy Cooperatives; Net Zero: Low Carbon Energy Generation; Net Zero: Renewables	Y02E (Production, distribution and transport of energy)	Electricity production - other	01 Offshore wind; 02 Onshore wind; 03 Solar; 04 Hydropower; 05 Other Renewable Electricity; 16 Nuclear power
Low-carbon heat and buildings	Green Economy: Homes and Buildings; Net Zero: Building Technologies; Net Zero: Heating	Y02B (Buildings)	Buildings and building construction work; Constructions and construction works for civil engineering; Specialised construction works	08 Renewable heat; 09 Renewable combined heat and power; 10 Energy efficient lighting; 11 Energy efficient products;
Low-carbon transport	Green Economy: Low Carbon Transport; Net Zero: Low Emission Vehicles	Y02T (Transportation)	Wholesale and retail trade and repair services of motor vehicles and motorcycles; Rail transport; Buses, coaches, trams and similar public urban transport; Underground, metro other non-interurban rail services; Taxis and other renting of private cars with driver; Freight transport by road and removal services; Transport via pipeline; Water transport services; Air transport services; Warehousing and support services for	14 Low emission vehicles and infrastructure

Growing Clean Report Classification	TDC RTICS subsectors From Growing Clean Report	Patent	SIC description	Low Carbon Economy Categories
			transportation; Repair & maintenance of ships; Repair & maintenance of aircraft & spacecraft	
Clean commodities	CleanTech: Adapted Goods; CleanTech: Mining, Fuels and Biofuels	Y02E (Production, distribution and transport of energy)		06 Bioenergy; 07 Alternative fuels
Sustainable finance	Green Economy: Green Finance; Net Zero: Green Finance		Financial services, except insurance and pension funding; Insurance & Reinsurance; Pension funding; Services auxiliary to financial services and insurance services	
Water management	CleanTech: Water Processing	Y02W (Waste and wastewater)	Sewerage services; sewage sludge	

Appendix 3: BEIS Patent Codes (Martin & Verhoeven 2022)

BEIS developed a set of patent codes to be used to aid innovation programmes. These were developed from keywords in the Energy Needs Assessment (2019). Patents identified by the keywords were then sense-checked by BEIS engineers and given a degree of relevance. They considered the following:

- Design, process efficiency, yield improvement.
- Cost reduction.
- Renewable energy.
- GHG reduction to achieve Net Zero.
- Technological reliability and sustainability.
- Health, safety, and risk reduction.
- Scalability and storage capacity.
- Energy from waste and its management.
- The resulting codes were checked against academic literature. They also include the Y02 patent categories

Biomass & Bioenergy

Building Fabric

Carbon Capture, Use & Storage

Heating & Cooling

Hydrogen

Industrial Clean Innovation

Nuclear Fission

Offshore Wind

Smart Systems

Solar

Tidal Stream

Appendix 4: Overview of Metrics/Measures Reviewed

- Revealed Comparative Advantage (RCA): The share of product p in total exports by country i, divided by share of product p in global exports. If RCA>1, the country is assumed to be competitive in the product, as it exports more than its 'fair share'.
- Revealed Technological Advantage (RTA): RTA in a particular technology class measures the share of all UK patents in that class, divided by the share of all global patents that same technology class. These are adjusted so that they lie within between -1 and +1, so that numbers greater than zero reflect that a country is specialised in a particular area. This offers a proxy measure of the areas in which the UK is relatively more innovative, and where advantages and value have been realised in production, or could materialise in the future.
- Product-to-country Proximity: The proximity between a product p and a country c is calculated as the average product-to-product proximity between product p and all the products the country currently exports competitively. Product-to-country proximity is correlated with the probability of developing future competitiveness in a product.
- Product Complexity Index (PCI): The PCI ranks products according to the similarity of the countries that export them competitively. High PCI products, which are exported competitively by high ECI countries, tend to reflect more technologically sophisticated products, and vice versa for low PCI products. The PCI is often used as a proxy for the technological sophistication of a product.
- 'Green' product: Product with environmental benefits. Based on APEC, OECD and WTO lists of green goods, which have been filtered and categorised based on the methodology outlined in Mealy and Teytelboym, 2022.
- Green Competitive Strengths: Green products that a country exports competitively (RCA > 1).
- Green Opportunities: Green products that a country does not yet export competitively (RCA <1), but could develop competitiveness in going forward.
- 'Brown' product: A product whose use is likely to decline if the world successfully mitigates climate change. Based on the methodology outlined in Andres et al, 2023.
- Brown competitive exports: Brown products that a country exports competitively (RCA > 1).
- Brown Lock-in Index (BLI): The BLI measures a country's transition risk, based on the share of low-complexity brown products in its export basket.

- Product (Green) Transition Outlook: The Product Transition Outlook measures a brown product's average relatedness to non-brown (green) products, scaled by its average relatedness to all other products.
- Country (Green) Transition Outlook: The average (Green) Transition Outlook of brown products the country exports competitively.
- Hirschman-Herfindahl Index (HHI): Calculated at the product and sector level. Measures concentration in the global export market. Calculated by summing the square of each country's share in global exports of a product/sector.
- Betweenness Centrality: It is a measure of the number of times a given node lies on one of the paths between all pairs of nodes in the network (Wasserman and Faust, 1994)
- Closeness Centrality: It is a measure of the average shortest distance from each node to each other node in the network (Wasserman and Faust, 1994).

Supplemented from Andres & Mealy, 2023 and Curran et al 2022

Appendix 5: Top 15 Tags for Beauhurst's Industry Classification

Industries	N of Companies	% of Total
Renewable energy	1226	14.9%
Energy management and reduction	584	7.1%
Application software	440	5.3%
Heating, ventilation, air conditioning and mechanical and electrical systems	407	4.9%
Waste management and recycling	406	4.9%
Cars, motorcycles and other road vehicles	369	4.5%
Manufacturing	316	3.8%
Tradespeople and trade services	294	3.6%
Energy storage	267	3.2%
Data provision and analysis	253	3.1%
Electricity generation	219	2.7%
Electronics hardware	181	2.2%
Environmental consultancy	163	2.0%
Energy utilities	137	1.7%
Land, water and air management	135	1.6%

Appendix 6: Extract from Real Time Data Technology Tag Classifications Focusing on Renewables & Energy

Techs	Technology Group
solar panels	Renewables
solar pv	Renewables
renewable energy	Renewables
solar	Renewables
renewable energy systems	Renewables
wind	Renewables
solar thermal	Renewables
solar panel systems	Renewables
wind turbines	Renewables
solar power	Renewables
renewable energy projects	Renewables
solar panel	Renewables
renewable energy technology	Renewables
renewable energy solutions	Renewables
solar energy systems	Renewables
solar panel installation	Renewables
wind solar	Renewables
renewable energy technologies	Renewables
solar pv panels	Renewables
renewable energy generation	Renewables
hydro	Renewables
solar power systems	Renewables
solar photovoltaic systems	Renewables
wind turbine	Renewables
solar farms	Renewables
renewable	Renewables
renewable energy sources	Renewables
renewable energy storage	Renewables
renewables	Renewables
solar technology	Renewables
solar energy solutions	Renewables
solar powered water	Renewables
photovoltaic cells	Renewables
commercial solar pv	Renewables
solar pv installation	Renewables
solar pv systems	Renewables
solar panel installations	Renewables
solar photovoltaic	Renewables
solar energy generation	Renewables
wave tidal	Renewables
wave energy conversion	Renewables

Techs	Technology Group
wind power	Renewables
vertical axis wind	Renewables
offshore wind farms	Renewables
renewable non-renewable	Renewables
renewable energy production	Renewables
turbines	Renewables
hydroelectric river power	Renewables
tidal power solutions	Renewables
energy water	Renewables
water turbines	Renewables
energy efficient pumped-hydro	Renewables
tidal energy technologies	Renewables
hydro development schemes	Renewables
hydro kinetic devices	Renewables
hydroelectricity dam.	Renewables
hydrokinetic floating technology	Renewables
hydropower systems	Renewables
marine energy technology	Renewables
picostream hydropower technology	Renewables
wave energy harvesting	Renewables
tidal energy generation	Renewables
pv system installation	Renewables
concentrated solar power	Renewables
solar power generators	Renewables
solar power infrastructure	Renewables
solar power installation	Renewables
solar power purchase	Renewables
solar power solutions	Renewables
solar power technology	Renewables
space-based solar power	Renewables
zero-carbon solar power	Renewables
e-grid solar panel	Renewables
bespoke solar panels	Renewables
commercial solar panels	Renewables
floating solar panels	Renewables
grid-connected solar systems	Renewables
high-performance solar panels	Renewables
high-quality solar energy	Renewables
large-scale solar energy	Renewables
mobile solar panels	Renewables
polymer solar cell	Renewables
premium solar energy	Renewables
scalable solar	Renewables
solar energy	Renewables
solar energy panels	Renewables

Techs	Technology Group
solar energy technology	Renewables
solar equipment	Renewables
solar farm projects	Renewables
solar hot	Renewables
solar industry	Renewables
solar panel glass	Renewables
solar panel projects	Renewables
solar systems	Renewables
solar thermal systems	Renewables
solar thermal technology	Renewables
specialising solar	Renewables
utility-scale solar projects	Renewables
water-based solar panels	Renewables
dye-sensitised solar cells	Renewables
solar cells	Renewables
solar technologies	Renewables
bespoke solar pv	Renewables
pv biomass	Renewables
pv systems	Renewables
solar pv installations	Renewables
solar power installations	Renewables
microelectronics photovoltaics	Renewables
plumbing solar	Renewables
bespoke solar photovoltaic	Renewables

biomass	Energy
biomass boilers	Energy
hydrogen	Energy
biotechnology	Energy
energy saving technology	Energy
electricity	Energy
green hydrogen production	Energy
hydrogen production	Energy
hydrogen generation	Energy
biomass systems	Energy
biofuels	Energy
biogas	Energy
energy efficient	Energy
energy reduction technologies	Energy
energy efficiency	Energy
fuels chemicals	Energy
hydrogen fuel cell	Energy
power	Energy
energy solutions	Energy
clean energy	Energy
clean energy generation	Energy

Techs		Technology Group
clean energy technologies	Energy	
clean energy technology	Energy	
sustainable energy	Energy	
energy conversion	Energy	
energy trading	Energy	
retrofit technology	Energy	
biofuel production	Energy	
biogas energy production	Energy	
biogas production	Energy	
biomass biofuel	Energy	
biomass solar	Energy	
biomass wind	Energy	
biomass combustion plants	Energy	
biomass electrolysis technology	Energy	
biomass energy systems	Energy	
biomass plants	Energy	
biomass wood pellets	Energy	
biomass--energy initiatives	Energy	
chp biomass gasification	Energy	
heatpumps biomass	Energy	
micronised biomass	Energy	
plants biomass	Energy	
solar biomass-based	Energy	
enzymatic biofuel cells	Energy	
biofuel zero	Energy	
biogas electricity	Energy	
biomass-based electricity	Energy	
biodiesel processors	Energy	
bioelectrochemical technology	Energy	
biofuels platform	Energy	
biogas catalyst equipment	Energy	
biogas refuelling stations	Energy	
bioremediation	Energy	
biosensors	Energy	
biosensors energy	Energy	
biostimulants	Energy	
closed-loop bio-methane energy	Energy	
methane biogas	Energy	
carbon-negative biofuel	Energy	
fuel-efficient power	Energy	
renewable energy-efficient	Energy	
retrofitting energy-efficient	Energy	
sustainable energy-efficient	Energy	
low energy technologies	Energy	
energy reduction	Energy	

Techs	Technology Group
energy reduction equipment	Energy
energy reduction plans	Energy
energy saving measures	Energy
energy-saving products	Energy
energy-saving sanitation devices	Energy
energy-saving upgrades	Energy
electricity demand	Energy
electricity mini-grids	Energy
gas electricity	Energy
hydro-electricity solar-voltaic	Energy
mains electricity	Energy
green energy	Energy
green hydrogen	Energy
green hydrogen electrolysers	Energy
hydrogen storage solutions	Energy
h2 fuel	Energy
clean hydrogen production	Energy
industrial-scale hydrogen production	Energy
sustainable hydrogen production	Energy
hydrogen-based clean energy	Energy
hydrogen sustainable	Energy
sustainable hydrogen manufacturing	Energy
hydrogen fuel cells	Energy
zero-emission hydrogen fuel	Energy
zero-emission hydrogen fuelled	Energy
electric hydrogen	Energy
electro hydrogen generation	Energy
extracting hydrogen	Energy
graphene hydrogen	Energy
hydrogen ammonia	Energy
hydrogen carbon	Energy
hydrogen methanation	Energy
hydrogen fuels	Energy
hydrogen storage	Energy
hydrogen technology	Energy
hydrogen-based produce	Energy
hydrogen-based technologies	Energy
hydrogen-electric engines	Energy
natural hydrogen resources	Energy
natural hydrogen sources	Energy
renewable hydrogen technology	Energy
ryze hydrogen	Energy
smart hydrogen-based technologies	Energy
retrofit electrolyser system	Energy
cold plasma technologies	Energy

Techs	Technology Group
reactor technologies	Energy
fusion design	Energy
fusion technology	Energy
lead-cooled fast reactors	Energy
nuclear technology	energy
geothermal energy power	Energy
decentralised home energy	Energy
energy infrastructure services	Energy
e-grid solutions	Energy
grid connection solutions	Energy
energy production	Energy
energy production systems	Energy
clean energy manufacturing	Energy
clean energy solutions	Energy
clean energy transitions	Energy
low-emission sustainable energy	Energy
sustainable energy projects	Energy
sustainable energy services	Energy
sustainable petrochemical alternatives	Energy
alternative energy technologies	Energy
low carbon energy	Energy
low-carbon energy projects	Energy
low-carbon power plants	Energy
e-grid sites	Energy
alternative energy technology	Energy
bio-reactors	Energy
decentralised energy systems	energy
developing new reactor	energy
energy global	Energy
energy information	Energy
energy subsea	Energy
energy containers	Energy
energy grid	Energy
energy sector	Energy
energy systems	Energy
energy transmission	Energy
generator sets	Energy
high temperature energy	Energy
hybrid energy hubs	Energy
hybrid energy systems	Energy
micro-tubular solid oxide	Energy
offshore logistics	energy
pollution energy	Energy
researches nuclear fusion	Energy

Techs	Technology Group
synthetic fuels	Energy
turbo generators	Energy
wide-gap band semi-conductors	Energy
energy environmental	Energy
environmental power	Energy
energy environment	Energy
clean energy harvesting	Energy
energy harvesting technology	Energy
technology energy	Energy
carbon negative power	Energy
carbon-free energy technology	Energy
power generation	Energy
smart energy generation	Energy
water cooling towers	Energy
anaerobic digestion	Energy
anaerobic digestion projects	Energy
anaerobic digestion unit	Energy
anaerobic digester products	Energy

Appendix 7: Clustering Results

N	Type	Code	Label	Degree	Closeness	Betweenness
1	Industry	Agri & Farm	Agriculture, land farming and forestry	1	0.0044	0.00
2	Industry	App & Soft	Application Software	10	0.0081	177.32
3	Industry	Bic & Scoo	Bicycles and scooters	1	0.0061	0.00
4	Industry	Build & Accs	Building materials, tools and accessories	1	0.0047	0.00
5	Industry	Cars & Veh	Cars, motorcycles and other road vehicles	3	0.0070	7.96
6	Industry	Chem	Chemicals	1	0.0061	0.00
7	Industry	Coll & Del	Collection and delivery	1	0.0061	0.00
8	Industry	Data & Ana	Data provision and analysis	5	0.0058	12.33
9	Industry	Elec Gen	Electricity generation	3	0.0065	3.06
10	Industry	Elec Hard	Electronics hardware	2	0.0063	100.00
11	Industry	Ene Man	Energy management and reduction	13	0.0088	285.11
12	Industry	Ene Sto	Energy storage	4	0.0074	16.44
13	Industry	Ene Uti	Energy utilities	3	0.0072	10.25
14	Industry	Env Con	Environmental consultancy	3	0.0066	3.96
15	Industry	Fab & Tex	Fabrics and textiles	1	0.0050	0.00

N	Type	Code	Label	Degree	Closeness	Betweenness
16	Industry	Heat & Ven	Heating, ventilation, air conditioning and mechanical and electrical systems	6	0.0076	35.45
17	Industry	Equip & Mach	Heavy equipment and machinery	1	0.0061	0.00
18	Industry	Land, Wat & Air	Land, water and air management	1	0.0050	0.00
19	Industry	Manu	Manufacturing	6	0.0081	134.79
20	Industry	Mat Tech	Materials technology	1	0.0050	0.00
21	Industry	Oil & Gas	Oil and gas	1	0.0061	0.00
22	Industry	Pack & Print	Packaging and printing	1	0.0050	0.00
23	Industry	Part & Com	Parts and components	1	0.0056	0.00
24	Industry	Phys & Test	Physical product design, testing and quality assurance	1	0.0061	0.00
25	Industry	Plad & Rub	Plastics and rubber	2	0.0052	2.91
26	Industry	Prod Rent	Product rental and hire	1	0.0061	0.00
27	Industry	Prop & cont	Property development and construction	3	0.0064	14.33
28	Industry	Ren Ene	Renewable energy	11	0.0087	194.40
29	Industry	Rep & Man	Repair, maintenance and servicing	2	0.0062	0.57
30	Industry	Rob & Aut	Robots and automation	-	-	-
31	Industry	Sens	Sensors	1	0.0039	0.00

N	Type	Code	Label	Degree	Closeness	Betweenness
32	Industry	Trade	Tradespeople and trade services	6	0.0076	35.45
33	Industry	Waste & Rec	Waste management and recycling	8	0.0079	232.66
34	Tech	Agr	Agri and Aquaculture	2	0.0057	51.00
35	Tech	AI	AI	3	0.0064	8.59
36	Tech	Ana	Analytics & Reporting	3	0.0064	8.59
37	Tech	CCU	CCUS & Carbon Reduction	3	0.0068	7.68
38	Tech	Ene	Energy	14	0.0089	266.69
39	Tech	Mon	Monitoring	2	0.0058	2.32
40	Tech	pla	Digital platforms	1	0.0057	0.00
41	Tech	Ren	Renewables	14	0.0089	209.46
42	Tech	Ser	Services	3	0.0064	8.59
43	Tech	sof	software	6	0.0078	71.70
44	Tech	Tra	Transport	14	0.0089	389.52
45	Tech	Bui	Buildings & Construction	3	0.0063	54.00
46	Tech	ESB	Energy Storage & Batteries	9	0.0079	107.29
47	Tech	Hea	Heating & Cooling	8	0.0076	55.25
48	Tech	Sen	Sensors	2	0.0048	51.00

N	Type	Code	Label	Degree	Closeness	Betweenness
49	Tech	Con	Consultancy	2	0.0066	2.52
50	Tech	Red	Reduction	1	0.0061	0.00
51	Tech	Mat	Materials & Packaging	6	0.0067	172.68
52	Tech	Ele	Electrical	3	0.0062	1.76
53	Tech	Wat	Water Purification	3	0.0067	54.02
54	Tech	Rec	Recycling & Recovery	3	0.0067	30.33
55	Tech	Rob	Robotics	-	-	-