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Eco-innovation and Green Start-ups: An Evidence Review

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An Evidence Review

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CONTENTS

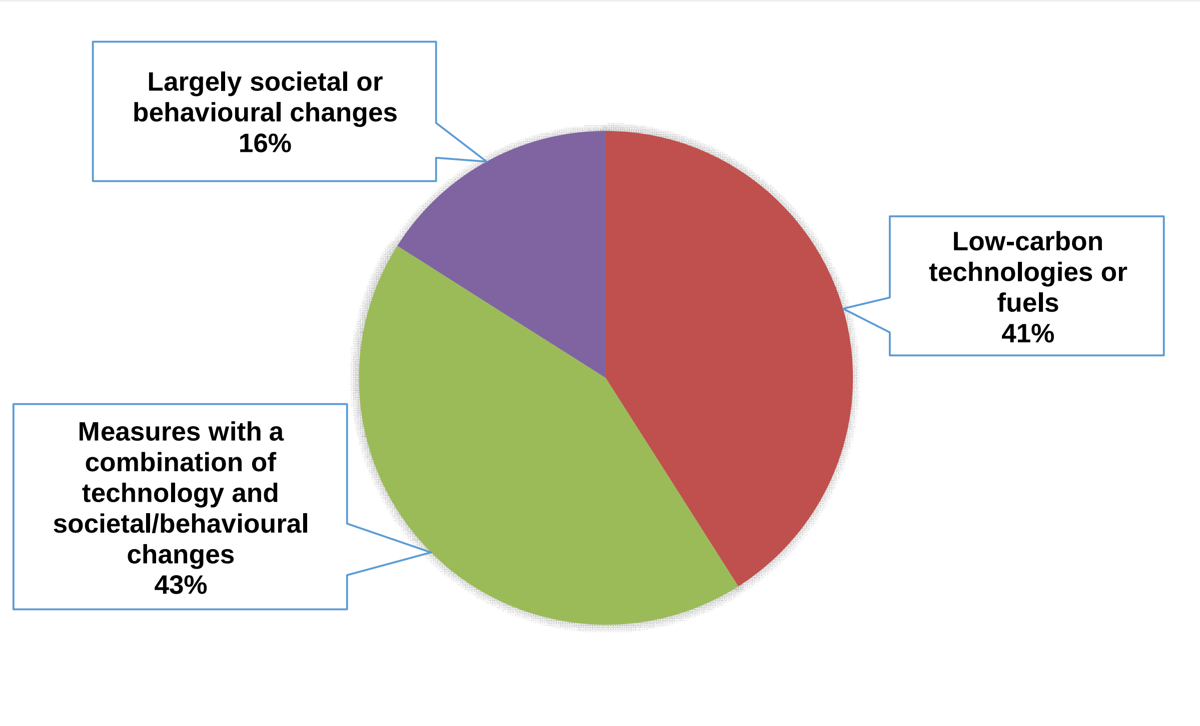
BACKGROUND

This paper examines ‘green’ start-up ventures and other forms of eco-innovation in which SMEs play an active role[1]. It reviews recent evidence on entrepreneurial and innovative initiatives that address specific environmental challenges, including the Climate Emergency. A companion report (ERC SOTA Review no. 51, July 2021), focuses on the closely related issue of improving environmental performance in the general SME population.

The UK Government has recently stated its commitment to accelerate environmental innovation, including: ‘fuel switching’ technologies, such as renewable electricity, biofuels and hydrogen; carbon capture and storage (CCS); digital technologies to increase the efficiency of production processes; and support for innovation-related research (BEIS 2021). This is part of a broader strategy which includes commitments by the UK Government and the devolved administrations to achieve Net Zero carbon emissions across the economy by 2050 (BEIS 2017, Climate Change Committee 2020). While new technologies (e.g. flow batteries, negative emissions technologies, and bio-plastics) need to play a prominent role in efforts to meet this target, it will also require large-scale social innovation, as people and organisations adapt to these changes. The Committee on Climate Change highlights this point by predicting that in their ‘balanced pathway’ scenario for achieving Net Zero, 43% of the changes needed will involve a combination of technological development and societal or behavioural change (Figure 1).

[1] While the primary focus of this review is on the roles played by SMEs and start-up ventures in eco-innovation, it necessarily refers to some examples, such as Carbon Capture and Storage, in which the main actors are larger corporations.

Figure 1: **Balance of technologies and societal / behavioural changes needed to achieve Net Zero**



Source: based on Climate Change Committee (2020): Figure B2.2.

The last two decades have seen significant achievements, notably the rapid growth in the UK's renewable electricity generation (BEIS, 2020). However, there are many outstanding challenges. For example, the widespread adoption of innovative technologies such as electric vehicles (EVs) demands transformative change in other sectors, such as energy generation and distribution (NAO, 2020: 12). Much of the local delivery of these changes will, in turn, depend on businesses operating in new or reconfigured 'green' industry sectors, including the various trades and professions who will implement solutions such as electric vehicle charging infrastructure, rooftop photovoltaic panels and building renovations.

The EU maintains an Eco-Innovation Scoreboard and Index, assessing the performance of Member States against 16 indicators spanning inputs (e.g. investment), activities (e.g. firm-level action), outputs (e.g. patents and publications) and outcomes (e.g. resource efficiency, socio-economic). A recent review of the period 2012-2021 found that research and development investment in eco-innovation had increased substantially, leading to progress made in resource efficiency and productivity outcomes, as well as greater public awareness (Al-Ajlani et al., 2021). Last assessed in 2019 before leaving the EU, the UK was scored above average in terms of eco-innovation inputs and activities, but slightly below for outputs and outcomes; indicating that the effectiveness of policies and investments could be improved (Graf, 2019).

It has long been recognised that innovations are the product of 'new combinations' and that entrepreneurs (of various kinds) play an active role in the process (Schumpeter [1911 / 1934], 2021: 65-66; Mathews, 2020). This review concentrates on the recent eco-innovation literature but also incorporates sources from the parallel and sometimes overlapping field of entrepreneurship. We use the term **'green' (or sustainability) start-ups** to refer to new and emerging commercial enterprises or ventures that are established with a primary aim of mitigating environmental impacts. They have been defined recently as, "startups that can contribute innovative solutions to societal and environmental challenges such as those identified by the United Nations' 17 Sustainable Development Goals" (Tiba et al., 2021: 1).

The composite term, **'eco-innovation'** has a broader scope, and is open to broader interpretation. Firstly, the word 'innovation' has itself been conceptualised, categorised, and interpreted a wide variety of ways[2]. Secondly, while the addition of the adjective 'eco' (or in some instances, 'green') suggests a process resulting in more environmentally benign products and services, there is no agreed procedure for determining whether this outcome is achieved in practice. This leaves the term open to accusations of 'greenwashing' and of relatively superficial or symbolic adoption of relevant environmental standards (Heras-Saizarbitoria et al., 2020). Lastly, the term 'eco-innovation' is often used to refer to a *deliberate attempt* to achieve a specified pro-environmental outcome. However, it has also been defined in terms of its *impact*, 'whether such an effect is intended or not' (OECD, 2009: 13; de Jesus Pacheo et al., 2017: 2279). In practice, other kinds of innovation may achieve similar results inadvertently. For example, smart phones have

[2] While fuller discussion is beyond the scope of the present review, we note that researchers often refer to different *types* of innovation output (e.g. 'product', 'process', 'business model'), their *scope* (e.g. 'component' and 'architectural'), and the *pace* or *extent* of change involved (e.g. 'incremental' and 'radical'). Innovation processes are also studied at different *levels of analysis* (e.g. organisation, supply chain, region, nation) and from different *disciplines* and *perspectives* (e.g. economics, network theory).

replaced the need for multiple devices such as satellite navigation and camcorders and associated need for resources (Suckling and Lee, 2015)[3].

In this paper, we begin by examining the latest evidence on green start-ups and different types of eco-innovation, outlining their main features and assessing their potential to contribute towards Net Zero targets and to address other environmental problems. We then review the main approaches that have been adopted to promote green start-ups and eco-innovations (of different types), analysing them in terms of the intervention type and their effectiveness in particular contexts. Building on this analysis, we identify several important gaps in the available evidence, presented in the form of a provisional research agenda and a short conclusion.

EVIDENCE

For the purposes of this review, we have divided the research literature on eco-innovation into three broad categories, based on their unit of focus and the disciplinary backgrounds of their authors[4]. Firstly, much of the technical literature on the development of specific technologies is derived from engineering and other STEM disciplines. Secondly, business school academics and economists tend to analyse innovation at the level of the individual and the firm, with particular attention being paid to the role of entrepreneurs. Finally, there is a growing body of interdisciplinary and multi-level research examining eco-innovation at a systemic level. This draws to varying degrees on the previous two categories, and has been conceptualised through the use of systems-based theoretical frameworks and models, including socio-technical transitions, circular economy and mission-oriented policy.

Environmental technologies

The system of Technology Readiness Levels (TRLs) was first developed by NASA in the 1970s to estimate the maturity of different technologies in the space industry. The ten levels span conceptual stages (TRL 0), to prototype development (TRLs 4-6), to full commercial application (TRL 9). The system has since been widely adopted and applied to eco-

[3] They rely, however, on energy-intensive ICT infrastructure such as data centres.
[4] We have adopted this simplified structure for presentational purposes and acknowledge that it masks significant overlaps and inter-connections between the categories.

innovations. For instance, the International Energy Agency uses TRLS to monitor the development over 400 individual technologies (IEA, 2020). Examples of early-stage technologies include nuclear fusion, and lithium-air batteries, while induction cookers and LED light-bulbs are commercial technologies, ready for widespread diffusion. The UK is considered a leading developer of clean technologies, and examples of those attracting significant attention and investment here include perovskite-based photovoltaics (TRL 4), autonomous and connected vehicles (TRL 6), and small modular nuclear reactors (TRL 6-9).

Table 1 groups categories of key technological innovations which will be needed to deliver Net Zero targets, together with some illustrative examples, and the typical policy measures taken to promote different kinds of innovation.

Table 1: **Technological eco-innovations**

Category of innovation	***Examples and indicative sources***	***Typical policy interventions***
Cleaner fuels	Renewable energy (solar photovoltaics, wind turbines, green hydrogen, etc.) (IEA, 2021)	R&D grants Funding for basic science Subsidies for diffusion
Resource and energy efficiency	Insulation fabrics (Rosenow et al., 2018) Appliance design (Scott et al., 2018)	Subsidies Minimum product standards
Negative emission technologies	Carbon capture and storage Direct air capture (Hepburn et al., 2019)	R&D grants International knowledge exchange
Energy storage	Lithium-ion batteries Phase-change materials Flow batteries Lithium-air batteries (de Sisternes et al., 2016)	R&D grants Demonstration projects
Smart technologies	Smart meters, thermostats, load shifting, vehicle-to-grid (BEIS and Ofgem, 2021) Industry 4.0 technologies in manufacturing (Bai et al., 2020)	Infrastructure investment R&D grants Demonstration projects Living lab experiments

Firm-level innovation

Business organisations have the potential to play central roles in eco-innovation, either by developing greener technologies, or as promoters of more environmentally sustainable practices, such as car-sharing and adopting vegetarian or vegan diets. Research on eco-innovation at the firm level is often found within the entrepreneurship literature[5]. In earlier studies, the primary focus was on identifying distinctive characteristics and motivations of so-called, 'ecopreneurs' (Gibbs, 2009, Kirkwood and Walton, 2010). This work suggested that founders of green start-ups had broadly similar motivations to those of other types of enterprise, with the exception of their concern for their environmental concerns. Over the last decade insights into individual ecopreneurs have been enhanced by incorporating comparative and multi-level approaches (Schneider, 2020: 163-185, Tiba et al., 2021). For example, while there is evidence that green start-ups and other small, pro-environmental ventures can often 'punch above their weight' by pioneering innovative products and services, researchers have also discovered that their longer-term impact generally depends on (and is reinforced by) close collaborative relationships with larger public and private sector organisations (Vickers and Lyon, 2014; Huybrechts and Haugh, 2018).

The evidence on green start-ups has highlighted an underlying heterogeneity in the types of business that have been studied. The terms 'ecopreneur' and 'ecopreneurship' have been applied to a wide range of organisational contexts, from small community-focused social enterprises and lifestyle-oriented micro-enterprises, to venture-funded start-ups in high technology fields such as biosciences (Schneider 2020). It is likely that these contextual factors are influential in shaping the characteristics and performance of these firms. For example, Jensen et al. (2020) found that the business strategies of Cleantech start-ups are more likely to be based on innovation and technological leadership, relative to their non-Cleantech counterparts – a difference that appears to be related to the founder's backgrounds in engineering (*ibid*: 903).

While the relative importance of their pro-environmental and commercial goals may vary, any organisation engaged in this field is likely to display some degree of hybridity as its owners and managers seek to combine these different institutional logics (Mair et al.,

[5] This work forms part of an emerging sub-field, often termed 'sustainable entrepreneurship'

2016). Researchers have examined the implications of hybridity both within and beyond the boundaries of the firm. For example, Reynolds and Holt (2021) showed how entrepreneurial founders navigate and resolve the inherent tensions, while York et al. (2016: 725) found that hybrid firms enjoyed a 'built-in flexibility' that broadened their appeal to key stakeholders, such as potential investors and business partners.

Trust and legitimacy research has also played a prominent role as green start-ups and other pro-environmental firms encounter and respond to periodic accusations of greenwashing (Skoglund, 2017). There is also a broader critique of these organisations, which questions their capacity to promote transformative societal change while also pursuing business models and trajectories shaped (to varying degrees), by commercial imperatives (Hultman et al., 2016). Organisations have responded to this in different ways, such as external engagement and advocacy (Stubbs 2016), and by undertaking life-cycle assessment (LCA) studies that seek to demonstrate the environmental credentials of their products, services, or business-models (Welling and Ryding, 2021).

In Table 2 we set out some of the more significant findings from these research strands, along with practical illustrations and tentative policy implications.

Table 2: Studying eco-innovation at firm level

Analytical framework	***Practical examples***	***Indicative sources***
Motivations and values of entrepreneurial founders	Distinguishing founder types, such as: 'Alternative actors' with non-market and lifestyle focus, 'Bioneers' developing eco-products and technologies for niche markets; 'Ecopreneurs' seeking growth opportunities; those holding strong environmental values.	Shaltegger (2002)
Firm-level resources, capabilities and strategic positioning	Distinguishing organisation types such as: 'Small and beautiful', with local/regional focus, 'Green knowledge economy', with high technology focus, and 'Green Collar Army', with labour-intensive and often regulation-driven focus.	Vickers and Lyon (2014)
Nature and implications of hybridity	Examining how sensemaking processes withing these organisations influence operational decision making, strategic direction and external social practices	Reynolds and Holt (2021)
Trust and legitimacy	Showing how B corps work to legitimise their business models by the through lobbying and advocacy work with influential actors, such as industry bodies and government officials	Stubbs (2016)
Alternative business models	Analysing the operational feasibility and environmental performance of sharing economy and P2P (peer to peer) innovations such as smart, city-based bike sharing schemes	Zhang and Mi (2018)

Systemic innovation

Most eco-innovations tend to combine technological advances with new ways of doing business. However, both of these elements are shaped by the broader social, economic, legal and political systems in which they operate. The most significant variations in the form and operation of green start-ups and eco-innovations are found across different industry sectors and geographic regions. While the underlying *sources* of variation may not be immediately obvious, they are often deeply embedded and resistant to change. Failure to take these factors into account can become a source of complex and hard-to-resolve challenges for the UK's policymakers and business practitioners.

Eco-innovation in different industry sectors

In some sectors, such as construction (both new build and retrofitting of existing building stock), many of the core technologies (insulation, lighting, glazing), are relatively mature, and the main opportunities for eco-innovation take the form of new business models and supportive institutional arrangements. In this instance, the further diffusion of eco-innovations often depends on how far 'middle actors', such as equipment manufacturers, merchants and installers, are able to reconfigure themselves in order to increase the scale and scope of their service delivery (Parag and Janda, 2014; Killip et al., 2020). Technological and socio-technical innovations can also have a transformative effect on particular businesses and industry sectors. For example, intensive R&D activity in the field of alternative protein sources (vegetable, insect and microbial) is creating new entrepreneurial opportunities for start-ups and existing businesses, while also exerting competitive pressures and sparking tensions in conventional livestock farming and associated industries (Fasolin et al., 2019; Sexton et al., 2019).

Eco-innovation in different cities and regions

Drawing on earlier work on the spatial dimensions of innovation and enterprise, researchers have analysed different places and spaces based on their distinctive characteristics. For example, Oxfordshire comprises a knowledge-based innovation ecosystem, with a thriving low-carbon sector generating more than £1.15bn in revenue (Patrick et al., 2014). By contrast the Humber and Teeside region is becoming the focus for hydrogen, wind and CCS technologies that build on its long industrial heritage, and ongoing capabilities in large scale manufacturing (Net Zero Teesside, 2021). There are also equally important, but less obvious examples of geographic specialisation, such London's role as a global centre for handling legal and financial arrangements for renewable energy projects.

Several studies have examined policy interventions that have attempted to promote eco-innovation by creating local and regional clusters of firms and other institutions. For example, Sarasini (2015) analyses the reasons behind the failure of the Nordic Climate Cluster, while Rossiter and Smith (2018) discuss how a cross-sector collaboration contributed to eco-innovation in the context of a regeneration project in inner city Nottingham. Such work is important because it can probe for the underlying reasons behind these varying outcomes. This is illustrated in a recent investigation into the transformation of urban ecosystems (Kroh, 2021); it emphasises the importance of well-structured, 'bottom up' processes that address technical aspects while also engaging and empowering local stakeholders.

Theoretical frameworks

There is a wide body of interdisciplinary research literature investigating eco-innovation at the system-level, including (1) 'socio-technical systems', (2) the 'circular economy', and (3) 'sustainable entrepreneurial ecosystems'.

Socio-technical systems (STS) literature focuses on interdependencies between technology, people, infrastructure, culture, and specific procedures and goals, and draws on earlier work on organisational change (Leavitt, 1962). It has been developed principally by researchers in the Netherlands and Scandinavia, and key specialisms include the Multi-Level Perspective (Geels, 2002), Strategic Niche Management (Hoogma et al., 2002), Transition Management (Loorbach and Rotmans, 2010). Initially, STS concepts were illustrated with reference to historical evidence, such as the transition from sailing ships to steamships (Geels, 2002). However, it has since become a leading framework for analysing contemporary patterns of environmental innovation, with researchers applying systems-thinking to investigate how new products, services, business models and public policies can disrupt fossil fuel-dependent economic activity (Sengers et al., 2019). Socio-technical *experimentation* attracts much scholarly attention in this literature, with interest in living laboratories projects in which new innovations are trialled in real-world environments.

The circular economy (CE) is an evolving concept that draws on multiple literatures, including supply chain management, logistics and engineering (Ghisellini et al., 2016). Core principles include the transformation of linear patterns of production and consumption into circular flows, based on the '3 Rs' principles of reducing, re-using and, recycling. It is also increasingly shaped by technological innovations, including the use of big data and artificial intelligence, along with organisational innovations such as the introduction of environmental management systems (EMS) and environmental management accounting

(EMA) (Scarpellini et al. 2020). The UK Government's CE priorities has been reflected in its 'Clean Growth Strategy' (BEIS, 2017) and emphasis on the development, manufacture and use of low carbon technologies, systems and services, most recently outlined in its 'Industrial Decarbonisation Strategy' (BEIS, 2021). In addition, UK-based organisations such as WRAP (the Waste and Resources Action Programme) and the Scottish Institute for Remanufacture (SIR), promote CE innovation to address specific resource and waste challenges. Evaluations of CE initiatives demonstrate substantial reductions in environmental impact[6]. However, given the complexity of the behavioural patterns and resource flows, there is evidence that so-called 'rebound effects', that can offset the benefits achieved in other areas (Ottelin et al. 2020).

Sustainable entrepreneurial ecosystems (SSE), is an emerging specialism within the entrepreneurial ecosystems (EE) literature (Boyd, 2006). EE is itself a relatively recent sub-field, which draws on more established bodies of research, most notably in relation to the spatial clustering of entrepreneurial activity. The biological metaphor has been deployed to highlight the close interconnections and mutual dependencies between entrepreneurial actors and other organisations, such banks, universities, and public sector agencies, that are active in a particular geographic location. Prominent examples of EEs include California's Silicon Valley and Israel's 'Start-Up Nation', centred around Tel Aviv, though the term has also been used to describe country-wide networks of incubators, accelerators, and innovation centres (Entrepreneurial Scotland, 2018). Reflecting these origins, the SEE literature places a strong emphasis on public policies that aim to promote start-up ventures. This may be a potential weakness, if it leads to a lack of attention being paid to incumbent firms. Recent evidence from the energy sector suggests that start-ups and incumbents play distinct and complementary roles during disruptive industry transformations, so both may be required to deliver sustainability goals (Palmié et al., 2021). SEE has proved a popular public policy solution, widely adopted by national and regional governments, though critics have highlighted other potential limitations related to its conceptual ambiguity and to the ways in which it has been translated into different contexts (Stam, 2015, Brown and

[6] It has also proved a particular strength for the UK, in comparison with other measures of eco-innovation; in its final Eco-Innovation Scoreboard and Index report the UK was ranked second for the implementation of resource efficiency actions among SMEs (Graf, 2019).

Mawson, 2019). Table 3 provides some recent examples of research on eco-innovation from each of these research strands.

Table 3: Analytical frameworks to study system-level innovation

Analytical framework	***Practical examples***	***Indicative sources***
Socio-technical transitions (STT)	Longitudinal studies of energy system change, including the development and diffusion of renewable energy technologies.	Geels et al., 2017; Wilson et al., 2020a
	Living laboratory experiments, which can span national demonstration projects, smart city trials, and community-led, neighbourhood-scale initiatives. Often involving combinations of technologies and different user types and practices.	Bulkeley et al., 2018; Sengers et al., 2019; Wilson et al., 2020b
Circular economy (CE)	Examining the development of the Maker movement (i.e. 'Fablabs' and similar collaborative work spaces), its success in creating new business models based on digital fabrication, and their potential contribution to increase the circularity of local production systems	Unterfrauner et al., 2019
Sustainable entrepreneurial ecosystems (SEE)	Comparative analysis to identify factors that promote the number of startups in SEEs around the world; provisional findings indicate a link to GDP and higher proportions of female founders	Tiba et al., 2021
	Examining activities of intermediary organisations in SEEs; indicates in addition to core tasks such as delivering advice and providing physical space for entrepreneurs, they play a key role in orchestrating collaborations	Hernández-Chea et al., 2021

EVIDENCE GAPS AND POLICY CHALLENGES

Research on eco-innovation spans a broad range of academic disciplines, from the technical sciences through to organisational and entrepreneurship studies, and across the social sciences. In response to the climate emergency, there is a need for further eco-innovation across the economy, and the research community has a crucial role to play in not only advancing science and technology, but also supporting businesses and policy makers in creating thriving innovation ecosystems.

Technological advancement

Many of the technologies needed to achieve Net Zero emissions are already well established, including for instance solar photovoltaics, wind turbines, EVs. However, there are opportunities for improvements in design and efficiency which can help accelerate diffusion. The engineering sciences play a crucial role in improving these technologies, and following the examples above, are developing Perovskite-based photovoltaics, floating wind turbines and more efficient, longer range electric vehicles.

Less mature technologies rely even more so on scientific research. Recent emphasis on Net Zero creates an imperative to advance so-called ‘negative emissions technologies’ to mitigate the effects of carbon emissions from difficult-to-decarbonise sectors such aviation or steel production. These include carbon capture and storage, direct air capture, and nature-based solutions.

However, technological advancement is not just the remit of university-based researchers. SME owners and managers are critical actors when it comes to developing and commercialising nascent environmental technologies. OxBotica and Arrival, for instance, are two Oxford University spin-outs developing connected and autonomous vehicles, while ITM Power is advancing green-hydrogen technology in the Yorkshire and Humber region.

Firm-level innovation

SMEs are also crucial for implementing much needed solutions, such as building energy efficiency retrofit, heat pumps, EV charging infrastructure and rooftop solar photovoltaics. With regards the decarbonisation of heat, it is often claimed that the UK has a shortage of skills for the rapid deployment of insulation, heat pumps and other efficiency solutions

(Jagger et al., 2013). However, slow progress can also be attributed to insufficient demand, which is a product of perceived high costs and disruption associated with installation, the relatively low price of natural gas (used for heating in most UK buildings), and inadequate government policy (Killip, 2020).

For green start-ups and other businesses wishing to promote the environmental benefits of their products and services, it can be difficult to choose between a plethora of environmental accreditations and guidelines – led by industry associations, local area networks, or government. There is a strong argument for researchers to work with industry and government to simplify and consolidate this landscape and to create a more recognisable, authoritative kitemark. This would enable SMEs to disaffirm greenwashing criticism, and give consumers confidence when making sustainable choices.

Another hindrance for SMEs is the difficulty and expense associated with proving the environmental benefits of their eco-innovations. Scientifically rigorous life-cycle-assessments (LCAs) and organisational carbon footprints can be expensive and time-consuming undertakings. In 2007, Tesco planned to conduct LCAs on all its own-brand products, but retreated from this goal once the costs and high margins of error became clear (Vaughan, 2012). Increasingly however, developments in artificial intelligence, 'big data' and the digitalisation of supply chains are helping to overcome these limitations (including in the agricultural sector, see: Liakos et al., 2018). These may help to make LCAs more accurate and affordable for green SMEs.

System-level innovation

The urgent need for deep decarbonisation across the economy means that eco-innovation can no longer be considered a market niche. Eradicating fossil-fuels from all sectors is now a national priority, presenting an unprecedented challenge with technological, organisational, social, economic, legal and political dimensions.

The research community will play a crucial role in providing the evidence to ensure that the transition is rapid, cost effective, and socially inclusive. This includes helping policy makers to create the conditions for market competition in sectors such as building energy efficiency retrofit: boosting demand with incentives, and improving supply through skills development and certification. It also includes supporting local authorities to develop low traffic neighbourhoods and electric vehicle charging infrastructure which meets the mobility and accessibility needs of all citizens. For instance, many urban councils have expressed a desire to create emissions zones and implement congestion charging, but the investment in fixed cameras and digital systems deployed in London are prohibitively expensive for smaller cities (Givoni, 2012). Alternative systems utilising smart technologies and mobile cameras could allow for more flexible charging, varying by time of day and even responding to local hot-spots of air pollution in real-time (Adams and Kanaroglou, 2016; Siemens, 2020). Such innovation not only relies on technological innovation, but requires new governance and institutional arrangements, and raises ethical questions about privacy, justice and inclusivity. The interconnected challenges associated with this example illustrate the need for collaboration between the research community, the private sector and government.

The nature of the zero-carbon transition will vary geographically, and different solutions will be needed for various economic sectors and socio-demographic groups. As eco-innovation attracts increased attention in the coming years, it is imperative that investments and policy interventions are aligned with the 'levelling-up' agenda, to ensure that the benefits of clean growth are fairly distributed across the UK. Teesside and Humber are benefiting from investment as hubs for the development of CCS and hydrogen technologies, helping to reverse decades of industrial decline. After leaving the EU and in advance of hosting COP 26, the UK is positioning itself as an international leader in zero carbon technologies and has set ambitious targets for emissions reductions and technology deployment (HM Government, 2020). While these intentions are laudable, the test will be in how much investment materialises in coming years, and the inclusion of eco-innovation in trade deals and post-pandemic recovery packages.

Our review of contemporary research evidence identified several theoretical traditions for investigating system-level change. While adopting different frameworks and subjects of interest, they share at least two commonalities.

Firstly, they highlight the significance of intermediary organisations in accelerating change (Kanda et al., 2020; Hernández-Chea et al., 2021). While government policy and individual consumer choices will be critical in achieving emissions reductions, the zero-carbon transition will be facilitated by myriad actors in the private and non-profit sectors who are responsible for installing technologies, providing advice and facilitating the circular economy. This includes trade associations such as the Federation of Master Builders in supporting their members to develop relevant skills and expertise to carry out deep-energy retrofits; or the Carbon Literacy Project, who help to educate and inform individuals and businesses about low-carbon living.

Secondly, it is imperative that the research community adopts an outward-facing stance. This will involve not only interdisciplinary working within the academy, but collaborations with private sector organisations and government. Living laboratory projects exemplify this partnership-working. In Oxfordshire, Project LEO brings together grassroots environmental groups with the electricity network operator and a team of engineers and social scientists to attempt to implement a smart, integrated energy system across the county, with equity and justice at its heart. While such local projects are valuable in testing and demonstrating eco-innovation, their success in achieving system-wide change depends on the ability to replicate elsewhere in the UK. Rigorous evaluation is therefore central to living laboratory projects, and it is important that the obstacles and challenges associated with complex collaborations are documented alongside successes.

Policy design and evaluation

Government policy already plays a critical role in providing the incentives, market conditions and rules and regulations needed to accelerate eco-innovation. Having set a target of achieving Net Zero by 2050, the scope and remit for policy intervention is set to expand in coming years. The National Audit Office (NAO, 2020: 51) has identified several key areas in which government has a role in delivering sufficient private sector investment to achieve the Net Zero targets:

- Sharing risks on projects and investments that the market cannot bear alone;
- Ensuring regulation requires monopoly infrastructure providers to invest in reinforcements that support the low-carbon transition, such as electricity networks expanding their capacity;
- Providing funding that supports research and innovation;
- Using levers such as legal obligations and influencing techniques to change business practices.

In expanding their reach and influence, policy makers will face a series of challenges. This includes the pressure to support individual technologies – often referred to as 'picking winners' – before it is clear which solutions will become widely adopted, and which will become out-competed or face insurmountable obstacles to development and diffusion. Examples of such choices facing the UK government include investing in potentially transformative technologies such as small modular nuclear reactors, nuclear fusion, and CCS; or subsidising established solutions such as EVs, solar photovoltaics and heat pumps, or investing in behaviour change and communication campaigns.

Mazzucato (2018) called for a shift from ‘challenge-led’ policies to mission-oriented eco-innovation, which involves working towards longer-term goals, and overcoming the fear of picking winners. She highlights the need for government to ‘tilt the playing field’ towards transformative change across sectors, and develop mechanisms so that the public and private sectors can share the risks, as well as the rewards, of innovation.

She also argues that to maximise the effectiveness of innovation policy, there is a need for better use of evaluation. The climate emergency demands that those commissioning and carrying out evaluations adapt their practices (Hampton et al., 2021). This includes better integrating evaluations into the policy-cycle; focusing on formative evaluation, using rapid assessment methods and improving international knowledge exchange.

Table 4 summarises this discussion of evidence gaps, raising indicative questions and highlighting implications for the research and policymaking community.

Table 4: Evidence gaps and research agenda

Nature of evidence gap	***Indicative questions***	***Implications for research and evidence-based policy***
Technological advancement	• What are the major barriers to advancing negative emission technologies? • What mix of policies are required to facilitated particular types of eco-innovation, such as large scale housing retrofits, EV adoption, or CCS?	• Balancing the need to support rapid technological advancement with the dangers of 'picking winners' and 'white elephants'.
Technology diffusion	• How can research help to accelerate the diffusion of established technologies? • How can SMEs be supported to lead the diffusion of sustainable technologies?	• Designing policy to create the conditions for a thriving energy efficiency retrofit market. • Designing well-targeted subsidy to support market development; judging when and how to phase it out.
Geography / regions	• At what level(s) (local, national, regional) should policies be introduced? • How can eco-innovation support the 'levelling up' agenda?	• Ensuring that the benefits of eco-innovation and public investment are distributed, capitalising on regional specialisms.
Sector based	• What solutions are available in difficult-to-decarbonise sectors such as aviation, cement, steel? • What is the role of intermediaries in facilitating eco-innovation in different sectors?	• Moving beyond thinking about the 'low carbon sector' towards economy-wide decarbonisation. • Supporting key industries to facilitate transformation, including construction and other trades; science, technology and research; legal and professional services.
Open innovation and IPR protection	• How can the interests of SMEs be balanced against efforts to promote inter-organisational collaboration?	• Balancing the need for public benefit, tax revenue and export opportunities.
Evaluation	• How can evaluation be improved and adapted in response to the climate emergency? • How can international knowledge exchange be enhanced for rapid learning? • How can long-term impacts be balanced with the need for quick results?	• Integrating evaluation findings into the policy cycle for continuous improvement. • Developing principles of adaptive management to utilise formative evaluation.

CONCLUSION

It is clear that the UK will need to promote many forms of eco-innovation in order to achieve its Net Zero ambitions, and to address other high-profile environmental problems such as air quality, water pollution and biodiversity loss. The composite term 'eco-innovation' is not well-defined. As a result, it remains vulnerable to misinterpretation and accusations of 'greenwash'. These limitations can be tackled through more focused research, as outlined in this review, coupled with improved communication with users to ensure effective implementation. This will need to be underpinned by strategic investments in R&D and further reinforced by a programme of rigorous, evidence-based standards setting.

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