

2021 Briefing paper

ACCELERATING CLIMATE INNOVATION IN LONDON

 Centre for Climate Change Innovation

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INTRODUCTION

Achieving London's net zero carbon target by 2030 will need concerted investment by government and require all business sectors and households to do more to reduce their environmental footprint. But it also creates new economic opportunities - specifically for innovators to develop, demonstrate and scale-up specialist climate solutions that drive the city's transformation.

These innovations have a vital role to play in achieving the ambitions set out in London's Green New Deal mission - doubling the size of London's green economy by 2030. London has all the ingredients to support climate innovations but barriers to successfully starting, commercialising, and deploying climate innovations still exist. In supporting the burgeoning climate innovation ecosystem, London has the opportunity to be a world-leading city in low carbon sustainable living - improving the health, wellbeing and prosperity of a growing population and enabling a just transition to a green economy while also building resilience through adaptation measures.

This paper outlines the need for a broad range of climate innovations in the context of achieving

London's net zero ambitions and addressing key environmental challenge areas. It also provides an overview of the global, UK and London context in relation to the ambitions to reach net zero and to adapt to a changing climate and highlights the range of environmental and socio-economic co-benefits resulting from implementing and mainstreaming new climate innovations. It concludes by reviewing the support required by innovators operating in this space, including specific challenges at the firm level for developing and deploying different types of solutions.

The intention of this paper is that it acts as a starting point for further in-depth analysis of the climate innovation landscape in different sub-sectors, along with their current strengths and development needs. It also sets the scene for further analysis on learnings from the global response to the COVID-19 pandemic and how these can be applied to the climate crisis.

Who is this paper for? The envisaged audiences are stakeholders promoting and supporting climate innovation in London as well as entrepreneurs and innovators.

Author: Danielle Davis, intern at CCCI and MSc student at Imperial College London

About the CCCI:

The Centre for Climate Change Innovation is an initiative of the Grantham Institute at Imperial College London and the Royal Institution. A multi-stakeholder partnership at the heart of the UK's climate change innovation community, the CCCI delivers technical and process solutions and service offerings that can reduce greenhouse gas emissions or help us adapt to the inevitable impacts of climate change. It aspires to develop a highly networked, inclusive, and integrated cleantech ecosystem in London that can stimulate and support the emergence of new businesses.

Find out more at: <https://www.imperial.ac.uk/grantham/innovation/what-we-do/>

KEY DEFINITIONS & TERMS

Climate innovation

We define climate innovation as creating and embedding innovative products, processes and services that remediate or avoid the environmental damage created by human activity. This covers the broad span of innovation typologies from deep tech and digital to non-technological innovations, which are created by researchers, start-ups, SME's, third-sector and large corporates.

Climate Innovation challenges areas

The capital's key environmental challenges, as detailed in the London Environment Strategy^[1], have been used as the starting point and proxy for defining the scope and breadth of climate innovation business sectors. It is however recognised that this does not cover all areas, notable exceptions include food systems and agriculture and manufacturing.

- Air quality
- Green infrastructure & biodiversity
- Ambient noise
- Clean energy
- Clean transport
- Energy efficient buildings
- Waste and recycling
- Circular economy
- Climate adaptation: extreme heat, water stress and flooding

INNOVATION AND THE TRANSITION TO NET ZERO

Innovation has a major part to play in meeting key climate and environmental milestones. In galvanising support, and setting priorities for investment, it is important to be clear why innovation is needed and how it contributes to London's environmental challenges. This section shares a perspective on the role of innovation within the context of global, UK and London environmental policies and climate ambition. In addition, it provides an overview of the types of innovation needed, both technological and non-technological, in achieving international, UK wide and London based climate goals.

Key Messages

- London's environmental and socio-economic challenges can be addressed by supporting new climate innovations to be developed and deployed in the capital
- We still need technological innovation with respect to developing new and improving existing technologies
- Broader innovation is equally as important, including new business processes, services and models from institutions, entrepreneurs, policymakers, industry, and the academic community

Global Ambitions

The United Nations (U.N.) Secretariat has called for "increased ambition and climate innovation" with respect to reducing emissions [2]. This is based on the latest reports showing a significant gap between the combined impact of the Paris Agreement member country's Nationally Determined Contributions (NDCs) and the emissions reductions required to stay within 1.5 degrees Celsius of warming [3]. To date, the climate action plans of parties to the Paris Agreement would reduce emissions by just 1% by 2030, compared to 2010 levels: significantly lower than the 45% reduction needed globally [4].

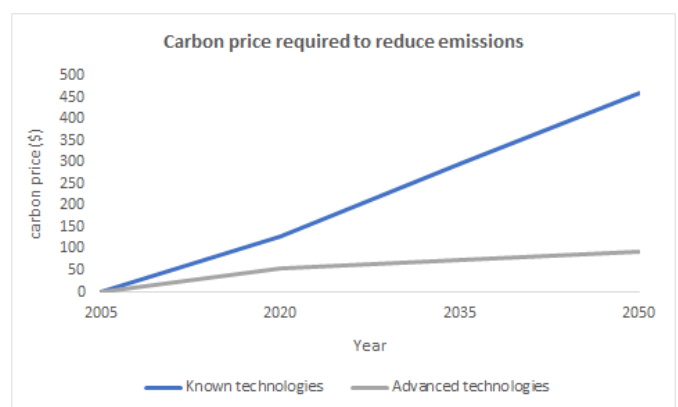
The U.N Climate Change* states that there is a need for disruptive climate solutions to accelerate low-emission and climate-resilient development. This includes transformations to our energy, land, urban, infrastructure and industrial systems, of a scale and speed upon which there is no historic precedent [5].

Technological innovation receives a significant amount of attention in the context of climate change innovation. It is often reported that most of the technologies needed to make these transformations happen, already exist. However, this can overlook the fact that the technology readiness and maturity of many of these technologies is low and in their current form they are not cost-effective options. For example, hydrogen and carbon capture utilisation and storage (CCUS) technologies still require significant development and investment. There are many others at early stages that need nurturing and investment for them to become commercially viable.

A 2009 study by Kyle et al., [6] modelling the value of

advanced technology in meeting 2050 green-house gas emissions targets, found a substantial difference in the carbon cost required for 1.5 degree pathways using known or advanced technologies. They highlighted the financial burden of relying solely on known technologies.

Figure 1. Global carbon prices needed to reduce emissions with and without advanced technologies (Adapted from: Kyle et al., 2009; OpenMind Innovation and Climate Change)



The International Energy Agency's (IEA) Global Roadmap to Net Zero ascertains that by 2050 almost half the reductions in CO2 emissions will need to come from technologies that are currently at the demonstration or prototype phase. They assert that major innovation efforts are required within the next decade to bring these new technologies to market in time and scale them up over the coming decades [7]. Furthermore, while mature technologies (e.g. onshore wind and solar PV) could be

*UN Climate Change is the United Nations Framework Convention on Climate Change (UNFCCC) secretariat tasked with supporting the global response to climate change

further improved, there is room for breakthrough innovations in areas including geothermal or concentrated solar power [8].

While technological innovation is critical in the global response to climate change, there is agreement that technology alone is not sufficient [9]. In addition to building on existing and developing new technologies, the global response needs to include novel, context-dependent advances with respect to how technology is deployed and commercialised. Developing innovative solutions to the widespread adoption and scale-up of technologies is a critical aspect of this that will require public buy-in.

"Innovation – the creation and diffusion of new ideas – is at the heart of the transition to a cleaner global environment. This includes not only technological innovation, but also innovation in economic and social systems and in lifestyles."

– Organisation for Economic Cooperation and Development (OECD) 2019 [10]

This requires all actors within the innovation ecosystem, including entrepreneurs, SME's, policymakers, investors and the academic community to innovate in pursuit of reaching global climate goals. This collective effort is reflected in the launch of the new UN Climate Change Innovation Hub (the hub) at COP26 in Glasgow this year. The hub's goal is to expand the scope for innovation on climate action by targeting enabling entities that are critical in the expansion and delivery of solutions. This includes bringing together multiple actors to collaborate and learn from each other to increase the adoption of existing technologies, as well as explore new products and value chains that are compatible with the 1.5-degree goal.

UK Plans to build back better

In April this year, it was announced that the UK would be increasing its NDC to 78% emissions reduction by 2035, setting the world's most ambitious climate target yet [11]. At the same time the UK Government has committed to increasing R&D spend to 2.4% of GDP by 2027 [12]. With a world-leading science and technology base and a high capacity for innovation, the UK is well positioned to lead when it comes to climate innovation.

The UK Government has outlined its increased support for innovation in the 2021 UK Innovation Strategy [13].

Furthermore, innovation has been recognised as a component of the economic recovery post COVID-19, and in achieving the UK's emissions reduction targets. A key tenant of the latest economic strategy is to build back "better, greener and faster" [14]. Underpinning this are three key pillars: innovation, skills and infrastructure. The report positions the transition to net zero as a key driver of growth, and shares plans to grow current net zero industries as well as encouraging emerging ones by ensuring better access to funding and ensuring the support of regulatory systems [15].

"...the UK is serious about protecting the health of our planet, while also seizing the new economic opportunities it will bring and capitalising on green technologies – yet another step as we build back greener from the pandemic and we lead the world towards a cleaner, more prosperous future for this generation and those to come".

– Kwasi Kwarteng, Business & Energy Secretary, 2021 [16]

The focus on innovation and net zero complements the 10 Point Industrial Plan published earlier in 2020, which states the UK's ambitions to become the world-leading centre for green technology and finance [17]. Investment in 'cleantech' is cited as being critical to realising this ambition, and to lead the world into the "Green Industrial Revolution" by commercialising low-carbon technologies, systems and business models in power, buildings, and industry [18].

Case study: Naked Energy – Redefining Solar Energy

London start-up Naked Energy have created the world's highest energy density solar technology that lowers operating costs and produces more energy on-site in the space available.

By optimising and building on current solar technology, Naked Energy are helping accelerate the transition to net zero by appealing to businesses that need to reduce their carbon emissions in a cost-effective way. While solar panels are an increasingly cost effective option to meet the energy needs of firms, the space available for them constrains their use.

As businesses look to decarbonise their operations, maximising the amount of renewable energy that can be produced on-site reduces the need for external carbon offsets.

Alongside this is a new net zero innovation portfolio, which earmarks £1 billion to fund projects in areas including offshore wind, energy storage and flexibility, hydrogen, carbon capture, utilisation and storage, low carbon fuels and disruptive technologies. This increased level of support for businesses is both exciting and essential, as currently the UK is not on track to meet future carbon budgets or the net-zero aligned NDC [19].

London at the forefront of climate innovation

London already holds a global reputation as a leader in digital, creative industries, fintech and life sciences, and has the opportunity to continue to strengthen its place on the world stage for climate innovation. In KPMG's recent Technology Innovation Hub Report, London was ranked second place against cities outside of the San Francisco/Silicon Valley region, for its ability to generate disruptive technologies that have a global impact [20].

This places London in a strong position to achieve its ambition to double the size of the green economy by 2030 and accelerate sustainable job creation. London's green economy has been growing. In 2019/20 the market for low carbon goods and services in London was worth £48 billion and employed 317,000 people across 14,000 businesses, up from £24 billion in 2006/7 [21]. London and the south-east are prime locations for climate innovation businesses, accounting for 42% of all 'cleantech' sales in the UK according to the London Environment Strategy [22].

Along with the ambition of reaching net-zero carbon by 2030, the Mayor of London has recently outlined plans for London to be a zero-pollution city by 2030 and a zero-waste city by 2050. The Green New Deal for London is setting the stage for London as a global leader for climate action and puts the environment at the core of the economic recovery through large scale investment in new technologies and innovation [23].

Funding the ambitious plans to tackle climate change and air pollution in the city is a constant challenge, and the Mayor of London is calling upon the private sector to help, recognising the economic benefits that can be realised from investing in climate innovation. Support for a cleantech cluster in West London is outlined in the

London Plan, and aims to draw together London's vibrant start-up community and leading universities to build a world-class ecosystem that helps the capital achieve its climate goals [24].

London policy sets a clear message that innovation not only provides an opportunity to improve economic prospects but is also a tool to improve the quality of life for Londoners. At a strategic level, the Government has outlined the need for 'good growth' which is emphasized in the London Plan, and is defined as: "growth that is socially and economically inclusive and environmentally sustainable" [25].

This sets the context for the focus on the just transition of the economy, and the role for innovation in recognising the importance of bringing everyone on the journey towards a lower carbon future. Public support has never been stronger, a 2020 poll found that 82% of respondents were concerned about climate change and 87% were motivated to prevent climate change [26]. In line with this, all of London's boroughs have declared a climate emergency, and have action plans to address these issues. Local authorities are in a unique position to act as delivery partners for the Government and have the ability to deliver long-term, sustainable emissions reductions in local places and to ensure that nobody is left behind in the transition to a green economy [27].

THE VALUE AND CO-BENEFITS OF CLIMATE INNOVATION

Alongside joining the global community in preventing the global climate from exceeding 1.5 degrees of warming and addressing broader cross-border ecological and environmental challenges, there are a range of socio-economic benefits to be gained from deploying new climate innovations. Below is a summary of the environmental, social, and economic benefits of climate innovation to London.

Key Messages

- Climate innovation has the potential to help achieve wider societal changes in pursuit of more sustainable development and improvements in quality of life for Londoners
- The specific value and contribution will depend on the types of innovations in more specific sub-sectors
- Measuring and articulating the socio-economic benefits is important in correctly valuing climate innovation and its contribution

The environment

The key mandate for climate innovation is to prevent the rising temperature to our planet as a result of anthropogenic green-house gas emissions. This threat to our environment and the impacts on human health and wellbeing is at the heart of the case for climate innovation. To accelerate climate action and increase its impact, climate innovation is increasingly being seen as needing to embrace systems innovation, which among other things involves tapping into opportunities for resource efficiency and applying circular economy principles. The circular economy (CE) is being adopted at an increasing pace by businesses looking to design out waste and pollution throughout their supply and value chains.

The financial sector is also acknowledging the benefits of CE strategies and is increasingly viewing CE as a de-risking strategy that reduces exposure to supply chain disruptions and volatility of resource prices as well as helping to regenerate the environment [28]. A recent Climate-KIC report suggests that by 2050, improving resource efficiency could simultaneously reduce global resource extraction by up to 28% and cut global green-house gas emissions by around 60% while also boosting the value of the world's economy [29].

In all major cities including London, there are direct consequences of a changing climate and increased likelihood of more extreme weather events. For London specifically, risks include: flash flooding, river flooding, heat waves and droughts [30]. Air pollution and biodiversity loss also have the potential to create positive feedback loops within the system that further exacerbate the pace of climate change, and amplify the environmental threat.

Aligned with this and other areas of environmental concern, the London Environment Strategy has set out the specific challenge areas for London. These revolve around nine themes: air quality, green infrastructure & biodiversity,

ambient noise, climate mitigation and energy, climate adaptation, waste, and low carbon circular economy [31]. While not all these areas are directly related to climate change, there are indirect impacts on the climate that can be harnessed from action in these areas.

London's environmental challenge areas are being addressed at the technological level, through inventive activity and innovation with respect to existing technology that can be applied in urban environments, but also through other types of non-technological innovation. This includes the development and implementation of nature-based solutions.

Case study: Clever Cities | Thamesmead Regeneration

Clever Cities is an innovative community-driven regeneration programme, working with social landlord Peabody in Thamesmead to create a healthier, greener environment for residents. The programme is based on local stakeholder participation and utilises nature-based solutions like parks, green spaces, and urban greening to help regenerate the local area and address urban challenges. Peabody has committed £1.2 billion to the programme, which makes it the largest regeneration project in London and is based on the understanding that the quality of the place people live has a huge bearing on their happiness and quality of life.

Through the creation of a 'Thamesmead Action Lab' Clever Cities aims to evaluate the social and economic value that nature-based solutions can deliver to the programme. This includes doorstep solutions such as rain gardens in courtyards and a wetland project to transform a polluted lake into a place people can enjoy and use for leisure and recreation are being trialled.

These are solutions that use landscape, planting, and nature to help provide environmental, social, and economic benefits. Examples of these include green spaces, parks and urban greening, which are increasingly being seen as a win-win for the environment and society as they can help mitigate against the effects of climate change and improve the environment.

Society and wellbeing

London's environment is directly linked to the health and wellbeing of its citizens. London's population is set to reach 11.1 million by 2050 putting further demands on the city and the systems that support it [32]. The London Environment Strategy highlights the socio-economic opportunities for the capital in pursuing a greener, cleaner city for a growing number of people. Benefits include cleaner air, green jobs, public health improvement from active travel and access to green space [33]. As the world recovers from the profound economic and social impacts brought on by the COVID-19 pandemic, support for climate action has only strengthened due to the emphasis on the relationship between our natural and societal systems. The same human activities that act as drivers of climate change and biodiversity loss also drive pandemic risk through their impacts on our environment. The need to rebuild in a way that provides resilience against future global threats while supporting a growing population in London is a priority for local government [34].

Furthermore, COVID-19 has highlighted the social inequalities that still exist. The outcomes of COVID-19 are not equal: the most deprived areas of London are almost a third more likely to be infected by COVID-19 than the least deprived [35]. The London Sustainable Development Commission (LSDC) highlights the social challenges at the heart of the climate and ecological challenges. Environmental degradation often affects the most disadvantaged members of our society the hardest, as exemplified by the pandemic. With a focus on achieving a 'just transition' to a greener and fairer society, the LSDC emphasize the need to "enhance our natural environment and resilience, reduce environmental inequalities, and boost green skills and jobs to build a zero-carbon circular economy." [36]

"How can we increase equity and widen prosperity whilst helping to avert the existential threat humanity has created for ourselves - and much else that co-habits with us on this planet."

– Ashok Sinha, LSDC Quality of Life Report 2017 [37]

Climate innovation aimed at reducing inequalities, bridging skills gaps, and ensuring that no one is left behind are key messages from the Government. Everybody needs to be able to afford to live lower carbon lives and prosper from the transition.

An environmental challenge of particular importance to societal health and wellbeing in London is air quality. Often discussed as the dual environmental challenge alongside climate change, air pollution is a serious issue that particularly affects the capital's most vulnerable who are more likely to be exposed to higher levels of ambient

air pollution. Researchers have even found a possible link between air pollution and human's susceptibility to COVID-19 [38]. The majority of this pollution is due to transportation connected with petrol and diesel engine vehicles. Reducing NOX and PM 2.5 to levels consistent with the World Health Organisation (WHO) guidelines would have significant health benefits and reduce the social and economic impact on the NHS. In 2010, air pollution contributed to between 3,500 and 9,400 deaths and cost £3.7 billion in healthcare [39]. There is a growing body of research highlighting the detrimental health impacts of air pollution in a range of ways from asthma, pulmonary disease and lung cancer, with links even being made to dementia. Children are particularly vulnerable to the effects of air pollution, which is concerning given that a third of London schools are near roads with NOx emissions over the legal limit [40].

Case study: The Tyre Collective

The Tyre Collective is an innovative London based start-up, that aims to safeguard our environment and health through the development of a patented new technology that captures the harmful particles emitted from tyres during use, all without having to replace the tyre.

Tyre wear is the second-largest microplastic pollutant in our ocean after single-use plastic and accounts for up to 50% of air particulate emission [41]. It is predicted to account for up to 10% of national emissions of particulate matter (PM) 2.5 by 2030. With the transition to Electric vehicles well on the way, making huge strides in reducing tailpipe emissions, tyre wear pollution may actually increase with the additional battery weight and torque [42].

In 2019, the Government made a call for solutions to address the challenge of air pollution from other sources, including brake and tyre wear. The Tyre Collective rose to the challenge, their prototype is able to capture up to 60% of airborne particles from a moving tyre and are working on a way to re-use the captured materials, closing the loop [43].

In addition to air quality, environmental improvements can contribute to tackling wider inequalities. Examples include improving energy efficiency to reduce fuel poverty, and improving the quality and equality of access to green space which in turn also contributes to boosting climate resilience.

The economy

The Innovation foundation NESTA asserts that: "an economy that succeeds in reducing emissions but does not protect or improve economic well-being is no more sustainable than one that is productive but fails to reduce". [44]

It has been predicted that by 2030, the green economy could represent as much as 10% of global market capitalisation [45], demonstrating the economic opportunity of a green economic transition. As previously stated, the London's Green New Deal aims to double the green economy by 2030 and sets the stage for a more equitable, greener pathway for rebuilding the economy

and is being seen as an important strategy as we emerge from the unprecedented economic downturn triggered by the global pandemic. While there are positive signals that an economic return to normal may be possible by the end of 2021, estimates suggested that global GDP may have taken a permanent hit by between 1-3% [46]. Innovative climate solutions are being lauded as a way to reinvigorate and regenerate the economy and to create new jobs, while also building resilience against future environment threats.

“By investing in green projects, we will help stimulate thousands of new jobs and create inclusive and sustainable growth that’s required to get us out of this crisis and transition to a future zero-carbon economy.”

– Shirley Rodrigues, London Deputy Mayor [47]

Support for capitalising on the economic opportunity of climate innovation is growing: there is recognition of the wealth of opportunity for innovators and entrepreneurs to create and capture the value of the transition to a greener economy. The emergence of new funding opportunities and programs demonstrates the Government’s commitment to innovation and supporting new ventures that help move the needle in favour of net zero and wider environmental and sustainable development goals.

“We will make the UK the best ecosystem in the world for starting and growing a business.”

– Build back better, 2021 [48]

Demonstrating and deploying technological or policy innovations in London has the benefit of acting as a testbed for their application elsewhere across the UK and globally. Achieving product-market fit with new climate innovations can be a challenge: in many cases there is no clear rule-book to follow [49]. Therefore, if climate innovations are successful in addressing key environmental, mitigation and adaptation challenges in London, scaling up geographically is an easier step to take. An example of this can be seen from the London congestion charging zone, which in its first year of operation reduced traffic congestion by 30%. This innovative policy has now been deployed in various forms across other major cities in the UK including Birmingham and Bath as well as globally including Milan, Stockholm and Singapore, to name a few [50].

Three sub-sectors of the green economy have been identified as part of the Green New Deal to receive fresh funding: retrofitting for buildings; low-carbon public transport and active transport and green skills. The Green New Deal’s ambition to guide investment towards a cleaner and fair economy will also help provide certainty to private investors, an important piece in the jigsaw to unlock innovation potential and finance green technologies.

A wider benefit to the economy of investing in low carbon technologies is the evidence for knowledge spillovers when compared with equivalent development of high carbon technologies. These spillovers have been found to be up to 40% higher for clean technologies [51]. This means that the development of new low carbon technologies can have economy-wide benefits which is important in helping achieve London achieve its economic goals.

The economic opportunity of climate innovation is also manifesting itself through more open avenues of innovation that sit outside of traditional R&D silos within firms. Open calls for solutions to challenges areas and competitions with prizes, including offers of funding are examples of ways in which this is happening.

What is Open Innovation?

Open innovation (OI) reinforces collaboration and co-creation as central tenants in developing solutions to real-world challenges. As a concept, OI encourages a diverse range of actors to contribute in creating new solutions, including: innovators, creatives, scientists, engineers, policy makers, financiers and business leaders. Open innovation pushes innovation beyond traditional organizational boundaries and making it a collaborative activity in pursuit of transformational change.

Case study: Schneider Electric and Sustainable Ventures

Schneider Electric recognise the value of open innovation in helping them achieve their decarbonisation goals, and in the development of innovative solutions that enable their customers to do the same. They have worked on 100 co-innovation projects with start-ups, and are strategically committed to working with entrepreneurs to turn new ideas, business models and technologies into bold solutions that align with their mission of a sustainable, electrified future.

Building on this, Schneider Electric has teamed up with cleantech innovation investor Sustainable Ventures to launch a new Open Energy Innovation programme. The aim is to support and fund new solutions and ideas that help solve the challenge of decarbonising global energy systems. The competition welcomes teams to submit solutions around data visibility, governance, insights and coordination that are critical in paving the way to a net zero energy system.

CLIMATE INNOVATION SUPPORT NEEDS

Innovators and entrepreneurs require support throughout the entire innovation journey. The type of support required depends on factors including the type of innovation and the technological readiness level (TRL) if the innovation is based on physical hardware. Below, the general support needs for innovators are discussed in this context, drawing out the different support needed for deep tech, digital and non-technological types of climate innovation.

Key Messages

- Public finance is important for deep tech innovation due to longer time horizons and uncertainties around the technology which can put off private investors
- The development and demonstration of innovations based around engineering and physical infrastructure requires dedicated prototyping, testing and demonstration facilities
- Support needs vary considerably for different climate innovation sub-sectors

General climate innovation needs

Support needs at different innovation life-cycle stages are outlined in Figure 2. While the information presented is in a linear form, innovation rarely happens in a linear manner, support needs will therefore be overlapping, and many elements may be happening simultaneously.

There is support that all innovation in this space requires to be successful including: finance, finding product market fit, finding the right talent and skills, leadership capabilities, workspace, and infrastructure. Support programmes including incubators and accelerators,

aimed at different stages of an SMEs maturity are valuable in providing the resources needed throughout the innovation journey and include functions such as access to industry mentors, peer-to-peer support and help with accessing patient capital. In addition, the concept of creating 'industry clusters', agglomerations of organisations working towards common goals in a specific location, like the cleantech cluster development supported by the Mayor in West London, has also been shown to be beneficial and helps raise the performance of innovators and entrepreneurs [52].

Figure 2. General innovation support needs at different stages of the innovation journey

	Innovation stage	TRL	Innovation support needs
Innovation Journey	1 Concept Development	1 & 2	R&D support, market analysis and competitor landscaping, as well as state-of-the-art in sub-sector theme.
	2 Proof of Concept	3 & 4	Test beds to build a trial products including where relevant technical validation and prototyping support & facilities. Understanding of standards and regulatory requirements that would impact product development or service offering.
	3 Demonstration Trials	5,6,7	<i>Insitu</i> , real-world demonstration of product/service, including access to locations or environments where products can be demonstrated and monitored. Support with IP and IP protection, as well as bid-grant application support from public funds.
	4 Market Entry	8 & 9	Commercial validation and go-to-market strategy support. Introductions to business partnerships, support accessing customers and public procurement opportunities.
	5 Scale-up	9	Workspace and infrastructure, as well as support finding the right talent & skills (especially business and technical skills) to expand the team. Access to private and investment, and support with regulatory approvals.
	6 Expansion	9	Market diversification support, both product and geographical. Access to the right talent, including experienced leaders able to manage rapid growth.

The London climate innovation ecosystem

A vibrant, well connected innovation ecosystem is essential to the development and deployment of innovative climate solutions. Cities can play a key role in bringing together the different actors in the ecosystem: innovators, universities, SME's, investors, the Government and corporate businesses to facilitate knowledge transfer and provide support services and infrastructure to support entrepreneurs and innovators and catalyse change.

London has all the components to support climate innovation, but there are opportunities to strengthen the ecosystem through a more joined up approach. Building connectivity within the climate-tech community is crucial to increase the pace of change: an imperative in addressing the climate emergency.

Specific challenges by innovation type

There are a number of ways to group different types of climate innovation, we have chosen three broad categories, un-related to sub-sectors, where there are some shared similarities in terms of the challenges for innovation. These groups are: deep tech, digital and non-technological innovations.

Deep Tech

Deep tech innovations are typically capital asset heavy; they rely on the development of physical products and hardware [53]. These types of innovations require significant financial capital throughout the innovation lifecycle to develop, prototype and trial the technologies and during the scale-up phase. Due to the risks inherent in developing these technologies and uncertain R&D timelines, private sources of funding are typically limited. For example, Carbon Capture and Storage (CCS) tech received only modest VC funding, in part due to the technology being unproven to work at all or cost effectively [54]. Innovations that require patient capital investment over a 10-15 year time horizon consistent with the development of deep tech, still struggle in the current UK equity market [55].

Due to this, Government funding and grants are a crucial source of finance for deep tech innovators. Recent initiatives that support enhancing government funding for R&D and deployment, to accelerate innovation include Mission Innovation 2.0, launched in 2021 with 25 member countries committing to raise investment in R&D and deployment by an additional \$5.8 billion annually [56] and Breakthrough Energy Coalition, a group of private investors aiming to finance early-stage energy innovations [57]. Support accessing finance is a key area for support, as well as help finding private investors willing to support capital intensive development. Private investment is often essential as many sources of public funding requires private sector matching. This has been identified by the UK Government Department for Business, Energy and Industrial Strategy (BEIS) as an area for improvement so that innovators can tap into these sources [58].

Professor Ramana Nanda at Imperial College London emphasizes the importance of financing the commercialisation of the technologies that will enable the UK to fully transition over from carbon-intensive sources of power such as coal and natural gas to fully renewable sources.

“New funding and organisational models at the nexus of research universities, philanthropy, and “patient” private capital have the potential to unlock vibrant [deep tech] innovation ecosystems that are urgently needed to solve some of the most pressing problems facing societies today.”

– Professor Ramana Nanda [59]

In addition to funding, the development of physical hardware also requires a different set of infrastructure and support services in which to develop, prototype, trial and demonstrate new technologies. Testing facilities in turn have their own innovation journey, often co-evolving with innovation of the devices and technologies that need to be trialled and tested themselves [60]. A lack of opportunities for SMEs to partner with universities and large corporates for investment in infrastructure is seen as a current barrier to scaling up solutions [61].

Finally, regulatory approval and standards mean that deep tech solution must often co-evolve with the input of government regulators to understand new innovations and overcome potential risks. It has been reported that the 'cycle time' for regulation in the UK is a reason that scale-up firms leave the UK and setup internationally. To date only two of the nine economic regulators in the UK are duty bound to consider innovation. This can cause delays to the uptake and adoption of innovations and put UK innovators at a disadvantage to competition in other countries [62]. To ensure the climate innovation can be swiftly deployed and scaled up, the Government has a role to play in ensuring stable policies and regulation that supports innovation. Understanding the implication of regulation and standards early on, can help start-ups and scale-ups address any barriers early on.

Digital-based

Digital-based innovations based on software development have much shorter innovation timelines. Often making novel use of data and advancements in general purpose technologies such as blockchain, AI, IoT or satellite imagery, they are in general more attractive prospects for private investment.

A key challenge area for these firms is the accessibility and availability of data. Organisations like the Open Data Institute together with Microsoft have been conducting research into climate change to identify priority areas for increased access to data through data collaborations [63]. There is a potential role for the Government in identifying the data we want to ensure is publicly available and putting in place the infrastructure and regulation to ensure there is a platform in which this can be collected and accessed. With an increasing emphasis on collaboration in pursuit of climate change, public and private sector organisations can play a role in contributing data, and support to innovators in accessing the data they need to make an impact is a key area challenge through new partnerships.

Non-technological solutions

Alongside deep tech and digital-based innovations, both which are rooted in technological innovation, there are a range of other relevant types of innovation that are equally important. This includes, but is not limited to:

- Business model innovation to deliver a product/service in a different way that helps reduce emissions or improve resource efficiency
- Innovation targeted at influencing consumer or public behaviours to lower emissions or protect the environment
- Innovation utilising nature, or the natural functions of healthy ecosystems for climate adaptation, mitigation, and biodiversity loss eg. Nature-based solutions or nature-based enterprises

Many of these innovations will leverage technology to support their goals and may even provide avenues or markets for the diffusion of new technologies, but the innovation itself is broader and is targeted at incremental process improvements, behaviour change or uses natural ecosystems to achieve the desired outcome.

The challenges for firms and innovators in this area are wide ranging and like deep tech, are likely to be constrained or supported by government policies and regulation. Perhaps more directly, they are reliant on the effectiveness of communicating the value of the solution to either the public, investors or stakeholders to gain adoption or funding.

The success of innovations aiming to change public or consumer behaviours, is largely reliant on the ability to

capture the imagination of large groups of the population to have an impact. This relies on creating compelling propositions that encourage societal wide changes in behaviour. This does not happen overnight and is often reliant on many changes across the whole system to make the transition possible. Taking mobility in London as an example, the Mayor of London has set the goal of 80% of all trips in London to be made by foot, bicycle or public transport by 2041 [64]. Changing transport preferences is only possible if the right options exist, and the infrastructure is there to support it. For this reason, this type of innovation needs to take into account progress across the whole system and requires a joined-up approach between actors within the system.

Nature-based enterprises (NBEs) are another example of a non-technological solution. NBEs use nature as a core part of their product or offering to drive economic activity. In doing so they also deliver many co-benefits that are particularly valuable to the public sector who are a major recipient of these solutions [65].

However, they face challenges in terms of a lack of awareness of nature-based solutions and the value they can deliver, and issues with securing public procurement opportunities due to a missing focus on environmental criteria as part of the procurement process.

There is a clear role for the Government in supporting non-technological innovation and helping firms overcome barriers to adoption. Whether that be through market signals, adoption incentives and subsidies, or investing in infrastructure that makes system wide change possible or re-aligning public procurement criteria.

In conclusion

The information presented in this briefing paper provides an insight into the valuable contribution that climate innovation can make to the economy and society at large in the context of creating a more prosperous, resilient and healthy London environment. It highlights how climate innovation is being supported at global, country and local city level in London, and the recognition that it is a vital strategy for addressing the threat of climate change.

“Climate has presented the biggest innovation opportunity of our life” – Dr Emily Shuckburgh [66]

A suggested next step would be to dive deeper into the specific sub-sector needs to map out the types of innovation needed to achieve specific environmental goals for London in the nine key challenges areas outlined in the Environmental Strategy. This would help act as a compass to enable targeted action aimed at removing barriers to climate innovation with the goal of generating specific innovation outcomes that would benefit the city. Additionally, comparisons between the global response to COVID-19 and that which is required to address climate innovation, is also an avenue for further analysis. There are undoubtedly key learnings we can take away and apply to the climate emergency, to accelerate mitigation and adaption, in pursuit of building a healthier, more prosperous, and resilient London.

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