Urban Foresight

CLEAN AIR TECH

Tackling air pollution in the UK through a more cohesive sector

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Urban Foresight

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EXECUTIVE SUMMARY

This report defines Clean Air Tech, the concept of a cohesive, growing Clean Air Tech sector and sets out recommendations to bring the sector to life.

SCOPING THE CLEAN AIR TECH SECTOR

Air pollution is the biggest environmental health threat in the UK and outdoor air pollution contributes to 40,000 excess premature deaths per year.[1] The rise of green and clean technologies, specifically those that tackle air pollution, has made strides in addressing both environmental and human health threats. However, the ecosystem in which technologies are developed, adopted and utilised in the UK to tackle air pollution is less understood.

The UK is notable in having several initiatives that encourage a whole systems approach to tackling air pollution. The Clean Air Strategic Priorities Fund (SPF), a UK Research and Innovation (UKRI) programme which will run until 2026, aims to enhance high-quality research and innovation that will help develop practical solutions to air quality issues and equip the UK to proactively tackle future air quality challenges. It includes stakeholders and experts across industry, academia, the third sector and more to better understand how air quality issues take shape and can be solved across sectors.

As part of the SPF, Innovate UK is interested in determining the best methods for encouraging the Clean Air Tech sector to coalesce, grow and prosper in the UK and abroad. The purposes of this research are to:

- Define Clean Air Tech;
- Identify the current state of the Clean Air Tech sector in the UK;
- Describe its current shape and functions;
- Set out recommendations to support its future.

This report is based on findings from an in-depth project methodology that took on a five-phase approach (Appendix I). This included desked-based research, a detailed interview programme with a range of stakeholders, a workshop and an online survey.

The background of air pollution as a global, national and local level issue is introduced. A Clean Air Tech definition is set out to support the future of a Clean Air Tech sector, and outlines the forces both supporting and restraining the sector's growth and cohesion.

Recommendations are presented for UKRI and Innovate UK, the UK Government, industry, and health professionals.

DEFINING 'CLEAN AIR TECH'

This research developed a definition, intended to act as a consistent way of defining the sector by Innovate UK, UKRI, and other public bodies:

"'Clean Air Tech' is any application of technology which monitors harmful air pollutants or results in cleaner air, both indoor and outdoor, through prevention, mitigation, or control of harmful airborne pollutants."

For the purposes of this research, harmful air pollutants are those with ambient air quality standards in the UK:

- Particulate matter (PM10)
- Fine particulate matter (PM2.5)
- Nitrogen oxides
- Ozone
- Sulphur dioxide
- Polycyclic aromatic hydrocarbons (PAHs)
- Benzene
- 1,3-butadiene
- Carbon monoxide
- Lead
- Nickel
- Cadmium
- Arsenic

It also considers ammonia and high levels of CO_2 to be harmful air pollutants – this is due to a focus on agricultural emissions and indoor air pollution that took shape throughout this research.

The definition is designed to expand in the future, to cover pollutants which can have negative health impacts, but do not currently have UK ambient air quality standards. This includes volatile organic compounds (VOCs), mould and pollen, micro and nano plastics, animal diseases, nuclear radiation, and natural pollutants such as volcanic ash.

As time goes on, further public awareness, research and policies will shape the list of harmful pollutants with ambient air quality standards in the UK.

Finally, this research understands that preventing harmful airborne pollutants from being emitted in the first place is the most effective way of ensuring clean air in the UK. While optimal, this is not always realistic and as such the definition focuses on prevention, mitigation or control of harmful airborne pollutants.

‘CLEAN AIR TECH’

is any application of technology which monitors harmful air pollutants or results in cleaner air, both indoor and outdoor, through prevention, mitigation, or control of harmful airborne pollutants.

Air pollution is the largest threat to environmental health in the UK

- → It contributes to between 26,000 and 38,000 deaths per year.
- → Those living in more deprived areas are often more exposed to air pollution and have less access to Clean Air Tech.***
- → Lived experiences are key to realising the societal benefits of Clean Air Tech.

SMEs play a prominent role in accelerating Clean Air Tech innovation. By 2027...

30%
of SMEs working in the Clean Air Tech sector expect their headcount to more than double.

50%
of SMEs working in the Clean Air Tech sector expect to more than double their turnover.

Over 50%
of SMEs already operate or provide services outside of the UK.

But, the Clean Air Tech sector lacks a sense of identity and cohesion

60%
of people working in the sector say it does not function well.

Nearly 75%
identified a lack of access to funding.

Almost 50%
reported unclear policy frameworks, lack of standards, lack of public awareness and poor recognition of the sector.

Clean Air Tech is an emerging sector in the UK

Clean Air Tech as a sector is a combination of business, organisations, government, academia, third sector organisations and passionate individuals that are working to tackle air pollution in the UK and beyond.

6 industries are the most active in the sector

- Professional, scientific and technical
- Manufacturing
- Electricity, gas, steam and air conditioning
- Education
- Transportation and storage
- Construction

A survey scoping the Clean Air Tech sector in the UK identified:

92,969
people working in the sector

- → 4x the number in advertising
- → 10,000 more than in Fintech*
- → Roughly the same number of farmers**

£51k – £191k
average turnover per employee

44%
expected staff growth by 2027

The Clean Air Tech Sector needs support

80% need funding support

63% want clear government messaging on clean air

54% need product innovation and R&D

42% support the idea of an industry alliance or network

35% desire a Clean Air Tech public body

31% need product commercialisation

*Trade.gov **Statista ***Chief Medical Officer's Annual Report 2022

FORCES AT PLAY

This research identified 36 individual factors shaping the future of the sector. These were categorised as either driving or restraining forces, falling into 6 categories:

1/ Evidence base

There is some awareness that air pollution is a major challenge – but this understanding is not widespread, and there are gaps in the evidence on the impact of pollution on health. This limits demand for Clean Air Tech.

2/ Relationship to market

There is demand for a wide range of Clean Air Tech products and services, and it can be difficult for innovators to break into markets.

3/ Applications of technology

Many Clean Air Tech applications are not standardised or certified and vary in quality. This applies to monitors and sensors in particular.

4/ Policy landscape

The UK has a Clean Air Strategy and a legislative framework – but it needs to be enforced. It also has significant gaps such as indoor air quality.

5/ Data

There are significant opportunities to measure and visualise air quality, but there is a lack of data standards, and existing data is often not used for action.

6/ Social aspects

Air quality is a social issue and there is an opportunity for companies to build better community engagement into their approaches – but at the moment, there is a disconnect between industry and the wider public.

RECOMMENDATIONS

This research identified a series of recommendations for Innovate UK and UKRI, government, industry and health professionals. Each of these recommendations is explained in detail in the report.

Table 1: Recommendations – from the section 'Bringing the Clean Air Tech Sector to Life'.

	Recommendations for Innovate UK and UKRI	Recommendations for Government	Recommendations for Industry	Recommendations for Health Professionals
MUST DO	Continue creating pathways to the Clean Air Tech market Focus innovation funding on high-end applications, particularly mitigation, analysis and sector-specific applications Create scale for more mature technologies Focus on knowledge transfer, building networks, and raising profile	Visible leadership from government Define and disseminate strong, clear messaging on air quality Strengthen and clarify legislative frameworks on air quality	Pay attention to market gaps Ensure quality over quantity	Get more involved Embed procedures within health and social care systems
SHOULD DO	Maintain and expand fundamental research portfolios Help innovators find customers through test-beds, living labs, and building SBRI-style initiatives	Create a new public body Establish standards for Clean Air Tech	Embed social principles during development stages Involve community research specialists	Formalise education and training for health professionals
COULD DO	Explore place-based demand		Invest in quick-win solutions and innovations	

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“This is the first time that we have considered ‘Clean Air Technology’ as a sector.

Up until now, we would not have considered ourselves to be a part of it – moving forward, we will.”

→ SURVEY RESPONDENT

INTRODUCTION

Tackling air pollution through a more cohesive sector

Air pollution is the largest environment health threat to the UK population.

As an "invisible" problem, experts, stakeholders and passionate individuals are faced with a unique challenge to come together as a sector to drive both awareness of and investment in Clean Air Tech.

Sector cohesion in practice does not happen overnight. It is also difficult to identify and appraise where it already exists. Pockets of cohesion occur throughout the UK on varying topics of air quality research and innovation. There are cohorts of researchers, innovators, government bodies and third sector organisations working in Clean Air Tech in the UK.

The Clean Air Strategic Priorities Fund (SPF) is a UK Research and Innovation (UKRI) programme which will run until 2026 and aims to support high-quality research and innovation that will help develop practical solutions to air quality issues and equip the UK to proactively tackle future air quality challenges.

As part of the SPF, Innovate UK is interested in determining the best methods for encouraging the 'Clean Air Tech' sector to coalesce, grow and prosper in the UK and abroad. The purposes of this research are to:

- Define Clean Air Tech;
- Identify the current state of Clean Air Tech sector in the UK;
- Describe its current shape and functions;
- Set out recommendations to support its future.

Prominent and well-funded industries like transportation, construction, and manufacturing address issues concerning air quality and emissions, but individuals may not consider themselves to be working in the Clean Air Tech sector.

This research reflects the idea that there is a desired state for the Clean Air Tech sector to achieve, and uses the word cohesion to represent this throughout. A cohesive sector brings industries together to share knowledge, best practice and lessons learned. It unites experts from research, the private sector and government. It collaborates across the sector to develop new innovations and creates additional capacity through these collaborations to address larger challenges. It identifies the most pressing environmental and human health needs and responds with effective innovations and solutions.

Importantly, it emphasises that Clean Air Tech is applicable to everyone, and there is not one industry that can tackle air pollution alone.

It generates revenue on the grounds that there is societal demand for technology, products and services that effectively tackle air pollution. It raises awareness on the importance of population behaviour change while driving market demand for sustainable business practices. Importantly, it emphasises that Clean Air Tech is applicable to everyone, and there is not one industry that can tackle air pollution alone.

AIR POLLUTION IN THE UK

A global threat

According to the World Health Organization (WHO), air pollution is defined as contamination of the indoor or outdoor environment by any chemical, physical or biological agent that modifies the natural characteristics of the atmosphere.[2] On a global scale, the combined effects of outdoor and indoor air pollution contribute to 7 million premature deaths annually. Case Study 1 illustrates how one source of air pollution, wood burning stoves, can impact on individual and population health.

Indoor air pollution

Air pollution can take place both indoors and outdoors. Indoor air quality is influenced by a range of pollutants mainly composed of particulate matter or gases.[1] Indoor air pollution can be caused by a range of items and activities in the home including:[2]

- Heating: burning wood or coal in stoves or open fires releases particulate matter, nitrogen dioxide and carbon monoxide.
- Cooking: frying and roasting release fine particles into the air.
- Damp and mould: damp conditions encourage mould and fungi to grow. These release spores into the home.
- Smoke: particles from tobacco smoke can be breathed in through the nose or mouth.
- Candles and incense: when burned candles and incense release fine particles and volatile organic compounds (VOCs) into the air.
- Cleaning and decorating: products such as washing detergents, air fresheners, carpet cleaners, deodorants, paints, and varnishes can contain VOCs.
- Building materials: building materials including asbestos, fibreglass, flooring materials, insulation, coating materials, and plastics can release VOCs and other air pollutants.[2]

CASE STUDY 1

THE USE OF WOOD BURNING STOVES IN THE UK

Image: Matt Seymour/Unsplash

Wood burning stoves have been found to contribute towards higher levels of indoor pollutants such as carbon monoxide, nitric acid, nitrogen dioxide and particulate matter.

These pollutants can enter into the indoor environment during fire starting and tending, and spread into the wider neighbourhood.[3]

It is currently estimated that around two-thirds of the UK population now use wood burning stoves in their homes.[4] Growing evidence links the use of wood burning stoves and the related indoor air pollution to acute inflammation of the respiratory system, asthma, allergic reactions, dementia, diabetes, heart disease, lung disease and mortality.[5]

The burning of wood in homes in the UK is responsible for £0.9 billion per year in health-related damages, about 40-times higher than that of a gas boiler.[4]

Asthma UK and British Lung Foundation have urged the UK population to only use wood burners if they have no alternative source of heat in their homes due to the risk this form of heating poses to human health.[5]

Indoor air pollution and its effects on human health are not well known. A wider evidence base on sources of indoor air pollutants, such as wood burning stoves, is needed to inform technology, products and services that tackle air pollution.

Outdoor air pollution

Outdoor air pollution has several components, including various gases as well as tiny particles of solids or liquids that are suspended in the air, often called ambient particulate matter. This type of pollution can occur naturally, as with dust storms or forest fires, but motor vehicles and manufacturing facilities are the main sources. Case Study 2 discusses one of the key sources of air pollution in the UK – ammonia emitted from agriculture.

In 1952, the City of London experienced 'The Great Smog,' where a heavy smog settled on the city for four days caused by a combination of coal burning and cold winter temperature inversion, trapping the smoke. An estimated 4,000 residents of London died due to the event and since then government has been slowly phasing out the use of coal and switching to cleaner, renewable energy sources.

The Great Smog was influential in defining air pollution as a threat in the UK. However, air pollution is not always visible. Across the country, monitored levels of air quality are regularly found to exceed legal limits in the UK.

In the UK, air pollution is the biggest environmental health threat and outdoor air pollution contributes to 40,000 excess premature deaths per year. This alone costs the UK economy upwards of £20 billion per year, not including deaths caused by indoor air pollution.[6]

There are significant knowledge gaps concerning how air pollutants interact with each other and their impacts on human health.

The Clean Air SPF has made significant progress in catalysing work within the clean air field. The Clean Air: Analysis and Solutions programme has invested £19.6 million in 18 research and innovation projects to encourage innovation in technology, policy, practice and systems. Additionally, £22 million has been used to fund a programme to investigate protecting human health in terms of the Clean Air Indoor/Outdoor Interface.[7]

CASE STUDY 2

UNDERSTANDING AMMONIA THROUGH CATCHMENT SENSITIVE FARMING

Image: Jo Anne McArthur/Unsplash

Ammonia is an air pollutant emitted as a by-product of agriculture and industry. It is involved in the formation of suphate and nitrate, which are precursors for PM2.5, one of the most hazardous air pollutants.[8]

In the UK, around 88% of ammonia emissions come from agriculture, where ammonia is lost to the environment from organic manures such as slurry and from the spreading of manufactured fertilisers.[9]

Breathed in at low-levels, ammonia can cause irritation to the eyes, nose and throat. Higher concentrations can cause burns and swelling in airways, damage to the lungs and result in death.[10] Exposure to PM2.5 is linked to further heart and lung related issues including non-fatal heart attacks, aggravated asthma and decreased lung function.[11]

Research has indicated that around one in five of all global deaths resulting from air pollution are due to ammonia emissions from agriculture.[8] More locally, a study in London found that 48% of all premature deaths in the city were caused by agricultural pollution.[8]

The UK Government has committed to reduce ammonia emissions by 16% in 2030 compared to 2005 levels. Changes to farming practices in relation to storage and spreading of organic manures, spreading of manufactured fertilisers, and livestock housing and diets, will help tackle air pollution in the UK.[9]

A CLIMATE HEALTH NEXUS

Environmental health risks of air pollution

Air pollution is not a new phenomenon – there are natural pollutants like those emitted during volcanic eruptions, forest fires or even spread from desert areas as suspended soils and dust. Case study 3 expands on natural pollutants in the UK. Other harmful air pollutants are largely caused by anthropological behaviours and lifestyle factors.

Several unnatural reactions to air pollution pose significant risk to the planet. When rainwater interacts with certain air pollutants, NO_2 and SO_2, it becomes more acidic than its natural level of pH. This is called acid rain. Acid rain is considered to be rainwater with a pH value of between 4.2–4.4 compared to the natural pH of rainwater which is 5.6. It can be fatal to natural ecosystems, particularly due to its impacts on soil. It also threatens wildlife and marine life.[12]

NO_2 is one of the key ingredients in producing algae. When water has high levels of minerals and nutrients that may cause excessive growth of algae, this is called eutrophication. Such excessive growth threatens the natural environment – potentially preventing photosynthesis and consuming large amounts of oxygen. This process does occur naturally but is happening at higher rates due emissions of NO_2 from transport, energy and agriculture.[12]

The differences between air pollutants and greenhouse gases tend to be identified based on their effects, despite being derived from many of the same sources. Air pollutants are substances with direct impacts on environmental and human health, while greenhouse gases pose indirect impacts by contributing to climate change.[12]

However, tackling harmful air pollutants and reducing greenhouse gas emissions in practice are not mutually exclusive. Oil, coal and gas, common sources of harmful air pollutants, are the largest contributors to global climate change, accounting for nearly 75% of global greenhouse gas emissions.[13]

CASE STUDY 3

SOLUTIONS TO TACKLING AIR POLLUTION IN ENVIRONMENTS

Image: Mick Garratt/Geograph

Wildfires are becoming increasingly commonplace due to climate change.

Globally, there is projected to be an increase of extreme fires of up to 30% by 2050.[14] This will have the knock-on effect of increased levels of air pollution. In the UK in 2018 a blaze broke out on Saddleworth Moor in the Peak District. Five million people were exposed to dangerous levels of PM2.5 for at least one day as a result of this fire.[15]

Firefighters are now looking to new technologies to enhance their ability to tackle these fires. Drones and satellites are being used to survey wildfire prone areas, and existing blazes. These technologies make use of Infrared Imaging, which can provide visual representations of the blaze despite the presence of smoke.[16]

The use of these technologies is enabling firefighters to intervene early to stop the spread of wildfires. This reduces the environmental damage and minimises the air pollution released.[16]

Human health risks of air pollution

Exposure to air pollution is linked to adverse health outcomes particularly related to heart and lung function.[17]

Pollutants such as particulate matter, nitrogen dioxide, sulphur dioxide and ammonia cause short term issues such as irritation of the nose and throat, coughs and shortness of breath. In the long term, the risk of diseases such as lung cancer, respiratory conditions, strokes and cardiovascular disease is increased. New evidence is also emerging linking air pollution to diabetes, low birth weights and dementia. Overall, this increases hospital admissions and reduces life expectancy.[1]

Health impacts associated with air pollution take place across the full life course. Certain groups are particularly vulnerable to exposure to air pollution, such as those with existing medical conditions and children (see Case Study 4). Air pollution is linked to slower lung development and the onset of atherosclerosis in children.[1]

Similarly, due to the uneven geographical distribution of air pollution, particular groups are at a higher risk of exposure and the related health impacts. For example, often socio-economically deprived communities live in areas with higher quantities of air pollution due to their proximity to main roads or industrial operations. As a result, they are more likely to experience negative health implications.[17]

In 2018 Public Health England named poor air quality as the largest environmental risk to public health in the UK. It is estimated that long term exposure to man-made air pollution causes the equivalent of 28,000 to 36,000 deaths every year.[1] Estimations suggest that if over 18 years the levels of fine particulate air pollution in England could reduce by 1µg/m^3 the following health issues could be prevented:

- 50,900 cases of coronary heart disease;
- 16,500 strokes;
- 9,300 cases of asthma;
- 4,200 cases of lung cancer.[1]

CASE STUDY 4

FIRST DEATH REPORTED TO BE CAUSED BY AIR POLLUTION

Image: Rosamund Adoo-Kissi-Debrah

Ella Adoo-Kissi-Debra's death certificate was the first death reported to be caused by air pollution.

Ella Adoo-Kissi-Debra lived in her family home near the South Circular Road in Lewisham, South East London. At around seven years old Ella was diagnosed with asthma. Her asthma was severe and over a two-year period Ella was admitted to hospital 27 times owing to the condition.[18]

In February 2013, at nine years of age, Ella suffered a fatal asthma attack. An inquest into her death concluded that Ella was exposed to 'excessive' levels of pollution and that air pollution had contributed to her death.[18]

For the first time in the UK, air pollution was listed as a cause of death on a death certificate. It was found that the levels of nitrogen dioxide in Ella's home exceeded both World Health Organization and European Union guidelines.[19]

Coroner Phillip Barlow, who dealt with the case, stated that there is 'no safe level of particulate matter' in the air.[19]

Ella's family have set up 'The Ella Roberta Foundation' to raise awareness of air pollution and campaign for air pollution guidelines to be followed by governments, councils, medical professionals and the general public at a global scale.

GREEN AND CLEAN TECHNOLOGIES

Clean Air Tech sits under the umbrella of green and clean technologies (greentech and cleantech). Green technology generally refers to the use of technology and science to create products and services that are environmentally friendly. Clean technology describes a range of products or services that improve operational performance while also reducing costs, energy consumption, waste, or negative effects on the environment. Greentech and cleantech are often used synonymously. However, the origins of both terms vary quite differently.[20]

Early forms of innovation aimed to reduce the emission of by-products from the coal industry. Since this time, the term green technology has been used broadly, to describe any process which aims to limit negative environmental impacts, from recycling, to nature-based solutions.

Greentech is now used to refer to a type of technology that is considered environmentally friendly based on its production process or its supply chain. It can refer to clean energy production, the use of alternative fuels, and technologies that are less harmful to the environment than fossil fuels. Greentech also encompasses several forms of environmental remediation, such as: alternative energy, electric vehicles, sustainable agriculture, recycling, and carbon capture.

Cleantech was popularised in the early 2000s by the founders of the Cleantech Venture Network (now Cleantech Group) as an increased number of venture capital investors were turning to green technologies after the collapse of the tech boom in 2001. Cleantech Group registered and acquired many cleantech related domain names and several cleantech related trademarks, though no trademark exists for the term cleantech itself. Since then, the term has come into wide use in the media, broader investment community and many underlying industries that make up the umbrella sector. Cleantech has now grown into the third largest venture capital investment sector behind IT and biotech.[20]

Within both greentech and cleantech, technologies, products and services could serve the purpose to make air “clean” (see Case Study 5).

CASE STUDY 5

A NEW PARTICLE SEPARATOR TO IMPROVE AIR QUALITY IS BEING DEVELOPED

Image: Evgeny Nelmin/Unsplash

Nano Control AB has been developing a new particle separator to remove pollutants such as soot, dust, and mist oil.

So far, this technology has been demonstrated in construction and heavy-duty truck industries, however it is applicable to any industries in which dust is released.

The new technology separates solid particles using multiple stages, starting with the largest particles and then working its way down to the smaller particles. An additional module can also be added to meet higher purification requirements.

It uses low quantities of energy and delivers a cleaner working environment. Disseminating this technology throughout multiple industries such as construction, mining, chemical, and coal will assist in reducing air pollution and decreasing the greenhouse effect.

It is not yet on the market however it is seeking partners to begin commercialising the new technology.[21]

INNOVATION AND THE RISE OF CLEAN AIR TECH

Innovation refers to a new idea, method or device that transforms the way that society operates.[22] It has been pivotal to addressing environmental challenges such as combating pollution and reducing the impact of climate change.[23] Tightening environmental regulations particularly incentivizes innovation in products, processes and systems to meet the requirements of those regulations.[24]

This has been the case for air pollution. Requirements have been put in place to regulate the environmental impact of industry and other activities on the quality of the air. This is owing to the recognition that clean air is essential to life. The World Health Organization (WHO) defines clean air as a basic human right. As a result of clean air legislation, new markets for clean air technology have emerged.[23]

Technical systems and products have been developed to monitor and track air pollution. Sensors have been developed and installed, particularly in urban areas, to inform town planners, researchers and communities about the most and least polluted areas and routes.[23]

Developments in pollution prevention, control and removal have also taken place. Catalytic converters have been developed to reduce pollutants produced from car exhausts.[23] Scrubber technology has been developed for industrial plants to minimise the release of harmful particles.[24] Case Study 6 provides another example of this kind of technology.

Innovation has also taken place to change processes to prevent emission in the first place. Renewable energy sources such as solar, hydroelectric and wind power are increasingly used in place of traditional fossil fuels. This has the combined effect of reducing air pollution and climate change.[25]

Technological innovation driven by regulation has an important role in solving air pollution.

CASE STUDY 6

ULTRA LOW EMISSION DUST REMOVAL TECHNOLOGY

Image: Christian Wiediger/Unsplash

Bluetech Clean Air Alliance developed an ultra low emission dust removal product technology.

This technology uses a surface filtration method called nano-fibre filter material to filter dust particles from the air. This method is more effective and efficient than deep filtration methods that use a filter bag, as almost all of the particles concentrate on the surface of the filter material.

Dust particles accumulate on the filter surface, forming a layer of breathable dust cake. This reduces the potential for blockages as the dust is not able to permeate as far into the filter material. When installed into a cartridge filter, this surface filtration technology collects dust particles onto the filter cylinder. The air that is then discharged is purified.

This technology delivers both environmental and economic benefits. It meets ultra-clean emission requirements and is superior in removing ash compared to similar filter equipment. Additionally, the total cost of owning the system is lower than that of competing equipment.[26]

“Change is not going to be easy, but Clean Air Tech must be a priority for improving the longevity of the population.

Public buy-in and policies that encourage public buy-in are desperately required.”

→ SURVEY RESPONDENT

DEFINING CLEAN AIR TECH

A core purpose of this research was to define ‘Clean Air Tech’.

DEFINITION

This research developed a definition, intended to act as a consistent way of defining the sector by Innovate UK, UKRI, and other public bodies:

> ‘Clean Air Tech’ is any application of technology which monitors harmful air pollutants or results in cleaner air, both indoor and outdoor, through prevention, mitigation, or control of harmful airborne pollutants.”

For the purposes of this research, harmful air pollutants are those with ambient air quality standards in the UK: particulate matter (PM10), fine particulate matter (PM2.5), nitrogen oxides, ozone, sulphur dioxide, polycyclic aromatic hydrocarbons (PAHs), benzene, 1,3-butadiene, carbon monoxide, lead, nickel, cadmium and arsenic. It also considers ammonia and high levels of CO_2 to be harmful air pollutants – this is due to a focus on agricultural emissions and indoor air pollution that took shape throughout this research.

The definition is designed to expand in the future, to cover pollutants which can have negative health impacts, but do not currently have UK ambient air quality standards. This includes volatile organic compounds (VOCs), mould and pollen, micro and nano plastics, animal diseases, nuclear radiation, and natural pollutants such as volcanic ash.

As time goes on, further public awareness, research and policies will shape the list of harmful pollutants with ambient air quality standards in the UK.

Finally, this research understands that preventing harmful airborne pollutants from being emitted in the first place is the most effective way of ensuring clean air in the UK. While optimal, this is not always realistic and as such the definition focuses on prevention, mitigation or control of harmful airborne pollutants.

SCOPE

Arriving on a definition for Clean Air Tech was an iterative process, involving desk-based research, stakeholder engagement and sense-checking its purpose with existing market products and services.

This research found support for a more cohesive Clean Air Tech sector including a wider ecosystem of industries, sectors, stakeholders and public engagement working on matters relating to air quality research and innovation.

There are a variety of roles that technology takes in the fight against air pollution – from mitigation, prevention and control – that are supported by existing research, expanding evidence bases, public health and awareness campaigns and policies that signal national priorities on air quality.

Industry verticals in the green and clean technology sectors are present in the Clean Air Tech sector. These were important to this research to understand which stakeholders consider themselves to be in the Clean Air Tech sector or not.

The definition of Clean Air Tech focuses on applications of technology, products and services. This is to enable a clear understanding that the purposes of this report are to enhance technology and innovation at the intersection of environmental and human health concerns regarding air pollution.

However, the wider context of policy, behaviour change, and public awareness is key to the development of the sector. This is emphasised later in the report in the description of Clean Air Tech as a sector, rather than what Clean Air Tech is in itself.

Table 2: Scope of Clean Air Tech for this Research

	Element of Clean Air Tech Ecosystem	Description
IN SCOPE	**Identifying types and sources of pollution**	• Applications of technology that distinguish between natural and anthropogenic sources of air pollution • Applications of technology that identify sources of pollution – road transport, sources of smoke, burning fuel for heating or cooking, power generation, industry, farming etc.
	Mitigating emissions at their source	• Mitigation through source control via applications of technology – 'dry-scrubber' filters that eliminate ash and soot from exhaust fumes before they leave their source, catalytic technology that chemically transforms pollutants before they leave their source etc.
	Removing pollution from the atmosphere	• Applications of technology that remove pollution from the air – air purification
	Monitoring and data	• Global, national, regional and local monitoring and evaluation via applications of technology – quantifying health and environment impacts of exposure to air pollution (WHO, UNDP, The Environment Agency, Defra etc.) • Applications of technology that enable knowledge transfer • Data modelling and forecasting
OUT OF SCOPE	**Raising awareness**	• Public communications, media and advertisements that spread awareness of the health and environmental impacts of harmful air pollutants • Knowledge sharing from medical professionals • Knowledge transfer across businesses and innovators
	Reducing pollution through policy and behaviour change	• Regulations that promote behaviour change and prevent or reduce air pollution – public policies on business emission outputs, hospitality policies on smoke-free areas etc. • Personal lifestyle choices that prevent air pollution – limiting number of flights per year, transitions to clean cooking practices etc.

“Clean Air Tech finds itself between various ministerial departments just like many technology sectors do, but there is a lack of cross-sectoral activity taking place.”

→ SURVEY RESPONDENT

WHAT DOES CLEAN AIR TECH LOOK LIKE AS A SECTOR?

A cohesive Clean Air Tech sector would bring together the entire Clean Air Tech ecosystem to drive investment, innovation and public awareness on the importance of tackling air pollution.

CURRENT SHAPE

Classifications of sectors and industries vary from country to country.

The UK has a specific coding system for classifying sectors and sub-sectors, which are effective for traditional industries that produce raw materials or finished goods. Often, sectors like Clean Air Tech emerge on their own and are difficult to define. They do not necessarily fit into a single coded description and it would do the sector a disservice to compartmentalise it in this way.

Here, we describe the Clean Air Tech sector as a combination of all of the elements of the Clean Air Tech ecosystem – business, organisations, government, academia, third sector organisations and passionate individuals that are working to tackle air pollution. This could be from identifying types and sources of pollution, mitigating emissions at their source, removing pollution from the atmosphere, monitoring and data, raising awareness or reducing pollution through policy or behaviour change. This is largely based on the nature of Clean Air Tech: it emphasises that Clean Air Tech is applicable to everyone, and there is no one industry that can tackle air pollution alone.

Findings from this research suggest the following key characteristics of the sector as it exists today:

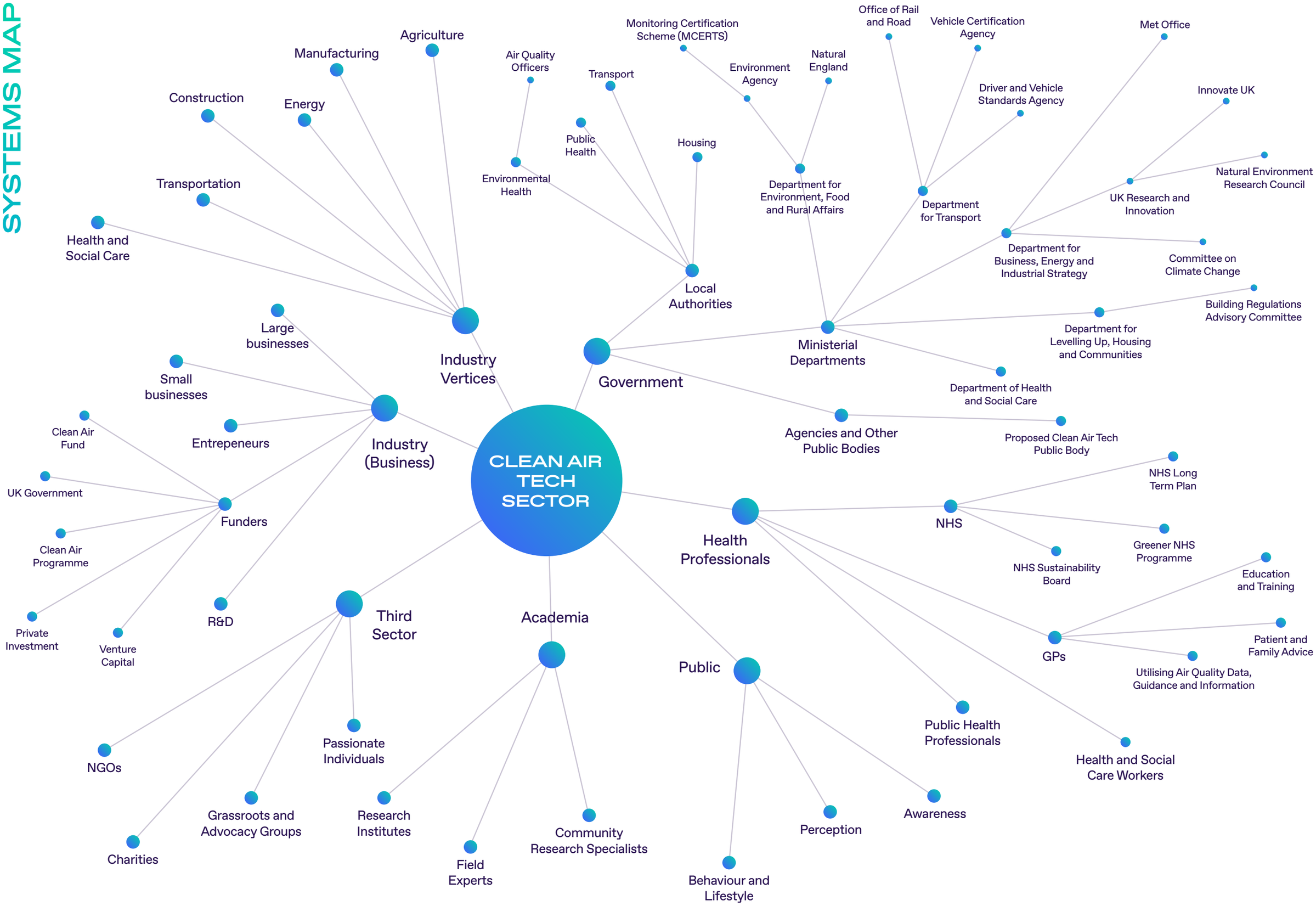
- The Clean Air Tech sector is emerging in the UK. Multiple organisations and companies are working in this space on disparate technologies and objectives. As a result, it lacks cohesion and unity. This is exacerbated by a lack of communication and collaboration between different industries working in the field.

- The sector also faces the challenge of a lack of awareness of the impacts of air pollution and a weak regulatory context. In order for markets to develop and grow, demand must be present for products and services. Without public awareness of the clean air agenda and the need for industry to comply to regulations, this demand will not exist.

- Standardisation is required to ensure that the products, technologies and services produced are monitored and quality controlled.

- There is a large scope for growth in the Clean Air Tech sector. New areas are emerging such as indoor air quality and the potential for co-benefits between net zero and air quality. However, stricter regulation with regards to air quality and environmental protection is required to catalyse this growth.

SYSTEMS MAP


CLEAN AIR TECH SECTOR
Government
Industry Vertices
Agriculture
Manufacturing
Construction
Energy
Transportation
Health and Social Care
Large businesses
Small businesses
Clean Air Fund
Entrepeneurs
Industry (Business)
UK Government
Clean Air Programme
Private Investment
Venture Capital
Funders
R&D
Air Quality Officers
Environmental Health
Transport
Public Health
Housing
Local Authorities
Monitoring Certification Scheme (MCERTS)
Environment Agency
Natural England
Department for Environment, Food and Rural Affairs
Office of Rail and Road
Vehicle Certification Agency
Driver and Vehicle Standards Agency
Department for Transport
Met Office
Innovate UK
Natural Environment Research Council
UK Research and Innovation
Department for Business, Energy and Industrial Strategy
Committee on Climate Change
Building Regulations Advisory Committee
Department for Levelling Up, Housing and Communities
Ministerial Departments
Department of Health and Social Care
Agencies and Other Public Bodies
Proposed Clean Air Tech Public Body
Third Sector
NGOs
Charities
Grassroots and Advocacy Groups
Passionate Individuals
Research Institutes
Academia
Field Experts
Community Research Specialists
Health Professionals
NHS
NHS Long Term Plan
NHS Sustainability Board
Greener NHS Programme
GPs
Education and Training
Patient and Family Advice
Utilising Air Quality Data, Guidance and Information
Public Health Professionals
Health and Social Care Workers
Public
Behaviour and Lifestyle
Perception
Awareness

FORCES AT PLAY

Driving and restraining forces contribute to the current shape of the Clean Air Tech sector. This research categories these forces into six categories:

1/ Evidence base

2/ Relationship to market

3/ Applications of technology

4/ Policy landscape

5/ Data

6/ Social aspects

The Force Field Analysis, overleaf, displays these interactions.

Evidence Base Relationship to Market Applications of Tech

Driving Force → (Positive forces supporting the Clean Air Tech sector)	← Restraining Force (Obstacles to a cohesive Clean Air Tech sector)
Air pollution is the biggest environmental health threat to the UK and various recent events have heightened public awareness on the impacts of air pollution.	There is a general lack of public awareness and knowledge on air quality and the impact that air pollution has on environmental and human health which holds the sector back and limits innovation.
There is an increased understanding that environmental and human health should not be siloed from each other.	The existing evidence base on the impacts of air pollution on human health needs further research and investment to better support sector needs.
Conversations on the relationship between net zero strategies and air quality are beginning to emerge, both to understand co-benefits of the two and the un-intended consequences that net zero could have on air quality.	There is a need to better understand the relationship between net zero strategies and clean air – some net zero strategies are emissions-intensive and some clean air practices are energy intensive.
There is an opportunity to show that clean air is an untapped market and worth investing in.	There is lack of incentive to produce data on air quality unless it is enforced – the more people know, the more money they need to spend on rectifying air quality issues.
There are a variety of monitoring, sensing and modelling products and services available in the market.	A lack of regulation on specific pollutants or polluting practices limits investment on new innovation.
There is room in the market for new products and services that target emissions at their source, target different pollutants, and address concerns on human health.	The outdoor Clean Air Tech market is competitive which could prevent industry cohesion in the sector. Indoor Clean Air Tech is still an emerging field.
Solutions to market barriers in the Clean Air Tech could include innovation challenges, smart awards, tax credits or patent pools.	The Clean Air Tech sector lacks adequate funding streams and pathways for entering the market. It is especially challenging for SMEs.
MCERTS, SEN, and ISO can be translated into an effective standards specific to Clean Air Tech.	Lack of standards and certification of Clean Air Tech limits the progression and quality of products and services in the UK.
Defra uses high-quality monitors to inform policy. Non-Defra-approved, “low-cost sensors” are widely accepted and used to measure air quality and checked against regional monitoring networks.	High-quality monitors are expensive and there is an oversaturated market of “low-cost sensors” that is confusing for consumers. Monitors and sensors can be unreliable, especially low-cost sensors which are sensitive to humidity, weather and location. They are also not robust enough for new pollutants, such as animal diseases.
Baseline technology already exists for Clean Air Tech, many monitors and sensors use the same patented technology with varying packaging and additional services.	There are not enough contract manufactures of Clean Air Tech in the UK. Low-cost, international equipment threatens the UK.

Policy Landscape Data Social Aspects

Driving Force → (Positive forces supporting the Clean Air Tech sector)	← Restraining Force (Obstacles for a cohesive Clean Air Tech sector)
The UK's Clean Air Strategy 2019 is considered to be progressive compared to other countries' national air quality ambitions.	The UK needs stricter policies on air pollution emissions that enforce business to change their practices.
There are a variety of best practice examples for the Clean Air Tech to adopt from countries that regulate indoor air quality such as Germany, Denmark and France.	There are currently no regulations on indoor air quality in the UK.
Brexit could mean that the UK can implement stricter monitoring limits and requirements than the EU. The UK could include elements that address air quality impacts on human health.	The current Clean Air Tech landscape is built around national monitoring limits and requirements from the EU. It is too early to say how Brexit impacts national priorities on air quality in the UK.
There is an immeasurable amount of data being produced every data on air quality in the UK.	Air quality data is not reaching the public realm compounded by a digital-divide and access issues.
There are opportunities to produce real-time data – maps and visuals showing air quality levels to support politicians, educators and health professionals.	Air quality data is currently not being used enough for action – in schools, hospitals, and political decision-making.
Unequal access to clean air in the UK can potentially be addressed by Clean Air Tech. Principles can be embedded from technology inception to address inequality, as those living in the most deprived areas of the UK currently facing the worst exposure to air pollution.	There is a disconnect between industry and the social and economic barriers that contribute to the impacts of air pollution in the UK.
Community-engaged research could remove barriers to understanding and accessing information on air quality. Citizen science approaches are already being implemented.	Technical terms of pollutants is a barrier to public awareness on air quality. It is difficult to communicate these terms to the public and explain how pollutants interact with each other.
Public health campaigns can be used to reduce emissions and lifestyle choices that contribute to air pollution.	There is a general cognitive dissonance in the general public regarding their lifestyle choices and how they contribute to the problem.

REGULATIONS

Air quality is a mix of reserved and devolved responsibility.

Scotland, Wales and Northern Ireland are responsible for concentrations of certain outdoor air pollutants. This includes monitoring these pollutants and developing nation-level responses to tackling air pollution. In England, tackling air pollution is a cross-government responsibility. Responsibility also falls under local authorities that have had statutory duties since 1995 to review and assess air quality and on a monthly basis designate any air quality management areas.

On a wider scale, the UK government is responsible for a core legislative framework and strategy to guide UK-wide air quality priorities. The legislative framework supporting the Clean Air Tech sector in the UK can be divided into three strands:

- **Ambient air quality:** improving the air that surrounds us;
- **Transboundary air pollutants:** imposing a national ceiling on the emissions of certain pollutants;
- **Managing and reducing emissions from key sources:** tackling air quality at source.

Ambient air quality

The first strand of legislation is that which governs ambient air quality – the quality of air that surrounds us. This originated in an EU Directive, Directive 2008/50/EC (the "Air Quality Directive"). The directive sets limits on the concentrations of different pollutants in the air. In the UK, responsibility to deliver ambient air quality is a devolved matter and is governed by a set of national regulations. Each of these national regulations have an associated clean air strategy covering each of the devolved nations, setting out how the standards will be achieved.

Transboundary air pollutants

The Gothenburg Protocol to Abate Acidification, Eutrophication and Ground-level Ozone sets national emission ceilings for four persistent air pollutants: Sulphur (SO_2), Nitrogen Oxides (NOx), volatile organic compounds (VOCs) and ammonia (NH_3). An amendment to the protocol in 2012 added PM2.5 to the list.

The Gothenburg Protocol national ceilings were enacted into EU law through the 2001 National Emission Ceilings Directive (NECD). The NECD 2001 was transposed into UK legislation by the National Emission Ceilings Regulations 2002. Member States report their emission inventories annually to the European Environment Agency (EEA) and the European Commission in order to monitor progress and verify compliance.

Following the UK's withdrawal from the European Union the legislation has been retained in domestic legislation in accordance with the EU (Withdrawal) Act 2018 (as amended) and subsequent regulations.

The UK has also enacted specific regulations to meet its international obligations on transboundary air pollutants, for example, the Air Quality (Domestic Solid Fuels Standards) (England) Regulations 2020 (SI 2020/1095), which apply in England. These regulations place restrictions on the sale of wet wood for domestic burning, limits on the emission of sulphur and smoke from manufactured solid fuels, and phase out the sale of bituminous coal (traditional house coal).

Managing and reducing emissions from key sources

Many commercial and industrial activities are a major source of pollutants. The main regulations in this area are derived again from EU legislation, the Medium Combustion Plan Directive (MCPD) and the Industrial Emissions Directive (IED). There are also transport regulations that control emissions from road vehicles (cars, vans and trucks) and impose a framework to manage emissions from shipping.

The MCPD covers combustion plants used to generate heat for large buildings. The directive was transposed into UK law by The Environmental Permitting (England and Wales) (Amendment) Regulations 2018 and by similar regulations in Scotland and Northern Ireland. The regulations require all plants in scope to be registered or permitted, and sets limits on the levels of pollutants that these plants can emit according to their type, size, age, fuel type and annual operating hours. It also requires operators to test emissions from their plants to demonstrate compliance with emission limits

The IED works in a slightly different way to the other air quality legislation. It requires industrial installation to use the 'Best Available Technology' that are able to prevent or minimise emissions and impacts on the environment.

Following the UK's withdrawal from the EU, the UK Government, in collaboration with the devolved administrations, is currently consulting on an approved list of Best Available Technology to be applied in the UK.

The first European exhaust emissions standard for passenger cars was introduced in 1970. There have been a series of updates to the standards with the 'Euro 6' Standard coming into effect in September 2015. This imposes emissions limitations for petrol and diesel engines. Following the emissions cheating scandal which highlighted how car manufacturers were able to game the emissions standards in laboratory testing of their engines, a new Real Driving Emissions standard was introduced in September 2017.

The nature of marine transport, the fact it is cross-border and sometimes operates outside legislative territories (i.e. in international water), means that there has not as yet been a comprehensive framework to manage emissions.

Therefore, the approach to managing emissions from marine transport is slightly different. There is a three pronged approach:

- steps to include marine transport in the EU emissions trading scheme;
- support for cleaner fuels and changes to the tax system to disincentivise the use of heavily polluting fuels;
- other measures, for example regulations that require vessels to use a shore electricity supply rather than run their engines when in port.

Domestic sources of regulation

In addition to the three strands of air quality legislation outlined above, which are all derived from EU or international legislation, there are a number of domestic air quality regulations, such as the Clean Air Act 1993, which provides powers for local authorities to designate smoke control areas.

The final element in the regulatory jigsaw is the **World Health Organisation's Global Air Quality Guidelines** covering particulate matter, ozone, nitrogen dioxide, sulphur dioxide and carbon monoxide. They provide guidance on thresholds and limits for key air pollutants that pose health risks.

They are guidelines and are not binding on any country unless that country chooses to adopt them into its own legislation. They have been used as part of the evidence for action by the UK Government in legal proceedings.

CLEAN AIR POLICY TIMELINE

1993

Clean Air Act 1993

Restrictions for industry and trade premises on factors such as the production of dark smoke, height of chimneys, contents and compositions of motor fuels.

2002

The National Emission Ceilings Regulations 2002

Regulations ensuring that total emissions within the UK do not exceed the amount specified for specific pollutants.

2010

Air Quality Standards Regulations 2010

Addresses air quality in relation to sulphur dioxide, nitrogen dioxide, oxides of nitrogen, particulate matter, lead, benzene, carbon monoxide, ozone, arsenic, and other pollutants.

Mandates the segregation of England into zones and agglomerations for the measurement of emissions thresholds and the review of these zones every five years and at times of dramatic changes in activities.

2017

The Clean Growth Strategy

Sets out action for delivering clean growth, defined as the development of the national income in line with a reduction in greenhouse gases.

Focus areas include low carbon technologies, processes and systems.

2018

The National Emission Ceilings Regulations 2018

Addresses anthropogenic atmospheric emissions by mandating the reporting of an inventory of emissions within the UK for the previous calendar year.

Health Matters: Air Pollution

Addresses the impacts of air pollution across a person's lifetime including action on reduction of air pollution for the NHS, healthcare professionals, local government, and the public.

Clean Air Fund

Aims to encourage local authorities to prioritise approaches that achieve compliance with legal limits.

Focus areas include introducing measures that make it attractive and affordable for individuals and businesses to change to cleaner modes of transport.

2019

Clean Air Strategy

Addresses how the UK Government will tackle all sources of air pollution to make air healthier to breathe, protect nature and boost the economy.

Sets out targets to reduce emissions of fine particulate matter, ammonia, nitrogen oxides, sulphur dioxide, non-methane VOCs by 2020 and 2030.

The National Air Pollution Control Programme

Sets out how the UK can meet legally binding 2020 and 2030 emission reduction commitments and provides a breakdown of smaller scale programmes working to reduce and manage air pollution across the UK until 2050.

2020

The Clean Air Programme

Funded by UKRI's Strategic Priorities Fund (SPF) and jointly delivered by research councils, government departments, non-departmental public bodies and devolved administrations. A total of £42.5m will be invested to catalyse research and investment into clean air.

Clean Air Zone Framework

Sets out the principles for the operation of Clean Air Zones in England. It provides the expected approach to be taken by local authorities when implementing and operating a Clean Air Zone.

UK Regional Clean Air Champions

An initiative also supported by UKRI's SPF, that brings together outstanding researchers across atmospheric, medical and social science to develop practical solutions for air quality issues and ensures that interdisciplinary communities are connected to the public and wider policy and business environment to maximise the impact of research.

2021

Air Quality Common Framework (Provisional Agreement)

Sets out the areas of retained EU law under consideration, current arrangements, and any elements from the policy that will not be considered.

SECTOR PARALLELS

The history of electric vehicle (EV) adoption could be viewed as a template for what is in store for the Clean Air Tech sector.

Modern EVs began to emerge during the late 20th century as manufacturers explored alternatives to conventional internal combustion engines (ICEs). This was driven by increased public understanding of the impacts of exhaust gas pollution as well as improvements in the underlying technology of electric cars.

In 1990, the California Air Resources Board introduced a program which would require 2% of vehicles sold by major manufacturers to be zero-emission EVs by the end of the century.[27] It was one of the first legislative attempts to target ICE vehicles from both the perspective of greenhouse gas reduction and improving health through air quality. This legislation, and others like it, helped to foster an environment of innovation in EV technology.

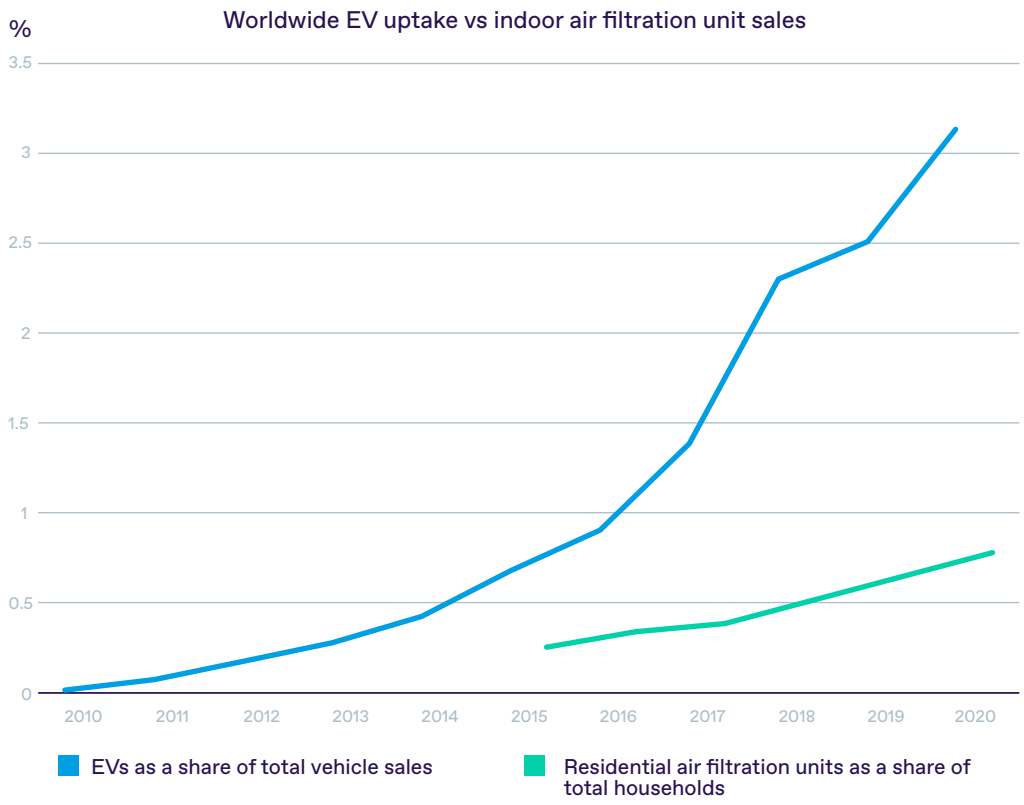
Over the last decade widespread international investment, the introduction of government incentives, and major shifts in focus of vehicle manufacturers have continued to fuel the rise of electrified transport. According to recent market analysis, 19 countries have now passed the critical 'tipping point' for EV adoption – where battery powered vehicles account for 5% of new vehicle sales.[28] This threshold marks the point at which there has been enough investment into overcoming early technological hurdles and consumer behaviour begins to shift. After this, in theory, significant investment in the old technology no longer makes sense and a runaway process of adoption takes place.

Recognising where these tipping points exist for Clean Air Tech could provide key insight into the right areas to target with legislation or financial incentives. This could be a certain concentration of air quality monitors within a region which triggers public awareness and widespread uptake, or the percentage of construction businesses using pollution-limiting machinery which leads to adoption across the sector.

As an example, comparison of the uptake of electric cars worldwide with the evolution of the market for indoor air filters helps to give some indication of what might be expected from the Clean Air Tech market in the next few years.

The graph below compares EV sales as a percentage of the total vehicles sold each year with the sale of air filters as an estimated percentage of worldwide households (2.3bn). Data for air filter sales is only available from 2015. The data indicates that, in this example, the clean air tech sector is progressing roughly as the EV market was 5 years before.[29,30]

Figure 1: Worldwide EV uptake vs indoor air filtration unit sales



INTERNATIONAL BENCHMARKING

> We can address global inequalities with solutions that tackle air pollution but it will be nearly impossible for a truly equitable response – air pollution takes on different forms depending on where you live."
>
> Interview participant

Navigating a diverse landscape

Although air pollution is a global issue, its effects are localised by country, region and community level determinants.

National responses vary, with countries having developed or in the process of developing their own strategies and standards for addressing air pollution. Each index is calculated differently.

At present, there is not an international air quality standard that allows countries to benchmark their performance on air quality levels or responses to tackling air pollution to each other. For example, the United States, India and Singapore all use a scale that ranges from 0 to 500 but the calculation procedures are different, and values are not comparable as a result. Air quality indices also differ in the importance given to each pollutant, often influenced by contextual factors – whether social, economic or even political.

Scoping exercise

A scoping exercise sought to capture a high-level comparison of how countries performed in relation to indicators of a Clean Air Tech sector. This looked at government strategy and national objectives; public health and environmental policy; research, innovation and funding; industry identity and collaboration; skills and education system; business environment; and third sector and charitable activity.

The exercise included evaluating 58 countries across North and South America, Africa, Europe, Asia and Oceania on their legislative frameworks relevant to air quality research and innovation.

Highlights from this process include:

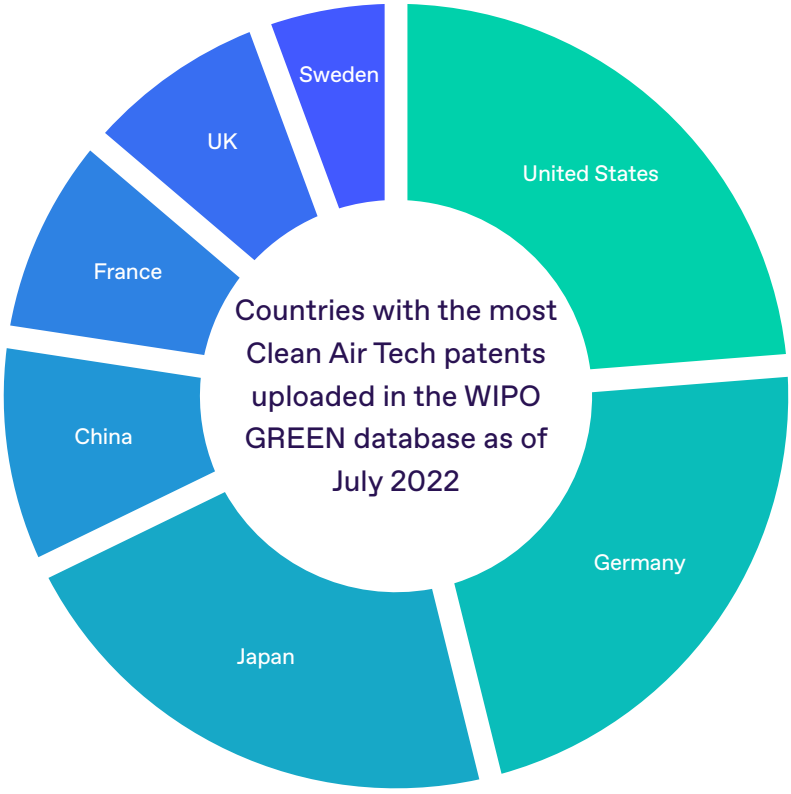
- All but three countries – Congo, Iran and Uganda – have legislative instruments containing ambient air quality standards. The types of instruments varied between national air quality acts, national environmental acts, policy/guidance and secondary legislation or more than one.
- Although most countries have legislative instruments that contain air quality standards, the list of pollutants included is not universal and countries with policies that act as recommendations or guidelines may not enforce action when breaches take place.
- Policies and legislation are significantly place-based: for example, Bangladesh has dedicated policies and legislation focused on brick kilns as a major source of air pollution, while the United Arab Emirates has laws focusing on clean indoor air environments.

Innovation insights

Although there is a lack of comparable datasets across countries on air quality and clean air technologies, this research sought out patent documents to provide insights on innovation related to Clean Air Tech using WIPO GREEN. This is an online platform for technology exchange, which includes patent documents from PATENTSCOPE as well as user uploads.

PATENTSCOPE is a free online search engine containing patent applications under the Patent Cooperation Treaty, patent documents from region patents offices, patent documents from many national patent collections including China, Japan, Korea and the United States. The search was filtered based on the category "pollution/waste: air: PATENTSCOPE uploads: technology."

Figure2: Analysis of Clean Air Tech patent uploads by country



The following countries had 20–40 patents in the WIPO GREEN database: Australia, Austria, Belgium, Canada, Denmark, Finland, India, Italy, Netherlands, Norway, Switzerland.

This approach has some limitations. WIPO GREEN is relatively new and it is not possible to understand the quality of the technologies uploaded on the platform. Patents alone will also not provide a full snapshot of innovation taking place – patents are expensive, developing countries may have weaker patent systems and innovation pipelines are different in each country.

Page 46 showcases the findings of high-level indicators that represent to what degree a Clean Air Tech sector exists in the top 7 countries identified to have the most patent uploads in the WIPO GREEN database as of July 2022.

High-level, international benchmarking of the Clean Air Tech sector

Key:

- **Basic/weak:** a lack of recognition and support of clean air and related technology
- **Intermediate/tentative:** recognition of the importance of clean air and a growing awareness of the potential of technology
- **Mature:** a strong recognition of the clean air agenda and ongoing work to maximise the role of technology

	Government Strategies/National Objectives	Public Health and Environmental Policy	Research, Innovation and Funding	Industry Identity and Collaboration	Skills and Education Systems	Business Environment	Third Sector and Charitable Activity
Sweden	Intermediate/ tentative	Intermediate/ tentative	Intermediate/ tentative	Intermediate/ tentative	Intermediate/ tentative	Intermediate/ tentative	Basic/weak
France	Mature	Intermediate/ tentative	Intermediate/ tentative	Intermediate/ tentative	Intermediate/ tentative	Intermediate/ tentative	Intermediate/ tentative
Germany	Intermediate/ tentative	Intermediate/ tentative	Intermediate/ tentative	Intermediate/ tentative	Intermediate/ tentative	Intermediate/ tentative	Intermediate/ tentative
China	Mature	Intermediate/ tentative	Mature	Mature	Mature	Mature	Basic/weak
Japan	Mature	Mature	Mature	Mature	Mature	Mature	Mature
South Korea	Mature	Intermediate/ tentative	Mature	Mature	Mature	Mature	Basic/weak
United States	Mature	Intermediate/ tentative	Mature	Mature	Mature	Mature	Mature
UK	Mature	Intermediate/ tentative	Mature	Intermediate/ tentative	Mature	Mature	Mature

“The question of market maturity is important and is driving uptake in new technologies, however the link to health is immature and not well defined.

We need to understand ‘by implementing x we have seen a saving of y’ in our public health spend, correlating to lives saved or greater awareness at the community level.’ These are key metrics that our company are trying to understand and to quantify.”

→ SURVEY RESPONDENT

BRINGING THE CLEAN AIR TECH SECTOR TO LIFE

The Clean Air Tech sector cannot be optimised on its own, or by one entity. In this section we set out recommendations for how Innovate UK and UKRI, government, industry and health professionals could support a cohesive Clean Air Tech sector.

Table 3: Recommendations for bringing the Clean Air Tech sector to life

	Recommendations for Innovate UK and UKRI	Recommendations for Government	Recommendations for Industry	Recommendations for Health Professionals
MUST DO	Continue creating pathways to the Clean Air Tech market Focus innovation funding on high-end applications, particularly mitigation, analysis and sector-specific applications Create scale for more mature technologies Focus on knowledge transfer, building networks, and raising profile	Visible leadership from government Define and disseminate strong, clear messaging on air quality Strengthen and clarify legislative frameworks on air quality	Pay attention to market gaps Ensure quality over quantity	Get more involved Embed procedures within health and social care systems
SHOULD DO	Maintain and expand fundamental research portfolios Help innovators find customers through test-beds, living labs, and building SBRI-style initiatives	Create a new public body Establish standards for Clean Air Tech	Embed social principles during development stages Involve community research specialists	Formalise education and training for health professionals
COULD DO	Explore place-based demand		Invest in quick-win solutions and innovations	

RECOMMENDATIONS FOR INNOVATE UK AND UKRI

Innovate UK and UKRI have a unique opportunity to bring forward the Clean Air Tech agenda as it relates to innovation.

1/ Continue creating pathways to the Clean Air Tech market

The UK has a range of well-studied barriers to innovation, particularly around commercialising research. Discussions of the 'valley of death' and the challenges of smaller innovators are common. This research suggests that all of these factors are present for clean air innovators – but on top of this, there are specific features which compound their difficulties.

There is a reliance on regulations to drive customer interest, there are gaps in the evidence base, and a lack of quality accreditation for products. Air pollution is also an "invisible" problem, which means innovations and solutions often do not deliver visible results.

UKRI has a range of programmes which aim to understand the experience of all SME innovators and improve their pathway to market: from changing the processes of public procurement, to creating different kinds of innovation funding, to capacity-building and skills for SMEs. All of these programmes should continue to support the Clean Air Tech sector. On top of these existing efforts, UKRI needs to consciously design innovation systems which tackle the specific barriers facing clean air. Innovate UK should continue to work with businesses, growing a network of supported SMEs and communicating success stories along the way.

> The sector has a lack of funders sitting within it – I would be very happy to see Innovate UK become more involved in providing funding opportunities and participating in public engagement on the topic."
>
> Interview participant

2/ Maintain and expand fundamental research portfolios

Pure science is the backbone of the Clean Air Tech sector in the UK. There are areas of significant research strength which represent both a source of future innovations, and an important reputation for quality which companies in the sector can draw upon. At a minimum, the funding available for the fields of atmospheric chemistry, public health, respiratory medicine, materials science, transport and environmental science need to be maintained.

This research identified several research gaps needed to inform a Clean Air Tech sector that responds effectively and responsibly to societal needs in tackling air pollution. The Clean Air SPF programme has made good progress with this work but more needs to be done to develop a wider evidence base on the following:

> Everyone knows about climate change but not everyone knows about air quality. We want to educate people to make the right choices and part of that is investing in finding the sweet spot between clean air, human health and net zero strategies."
>
> Interview participant

> We need a more active research community in Clean Air Tech, including expressions of interest from research councils on areas that need development."
>
> Interview participant

1. Indoor air quality and its impacts on human health;
2. The indoor-outdoor air quality continuum – how they interact with each other and their impacts on human health;
3. How net zero strategies can be used to tackle air pollution and the unintended consequences of net zero strategies on air quality, and vice versa;
4. The co-benefits of addressing environmental and human health concerns together under a 'one health' approach;
5. Toxicity levels of harmful air pollutants and how these toxicity levels impacts human health.

Maintaining existing research is important to ensuring that Clean Air Tech is supported by science. It is also important to expand research portfolios and fill the gaps identified in this research. At the moment, there is a vast amount of science that is not making its way into technology, products and services. Maintaining and expanding research portfolios is as much about ensuring the science is there to support innovation as it is creating links between what the science is telling us and the products reaching the market.

3/ Explore place-based demand

> Finding air quality information based on where you live is very difficult. Air quality data platforms combine information from different vendors and manufacturers but this does not always include privately deployed monitors based at high-emitting industrial sites."
>
> Interview participant

Other countries have developed air quality indicators which reflect their unique economic and geographic needs. UKRI's own research suggests that the benefit of place-based solutions will be greater than place-agnostic solutions.[33] Given clean air is fundamentally driven by demand from governments, one option would be to develop a set of place-based indicators in the UK. These would look at the exact combinations of pollutants which apply in a particular place, as a basis for innovators to develop solutions tailored to that need. For example:

- Councils report that odour is one of the largest complaints received from residents: odours usually indicates something has been emitted into the atmosphere. The relationship between localised environmental health complaints and air pollution could be further explored.
- Pollutants from specific factories or facilities often represent a major share of a places' emissions or pollutants and public health challenges: examples might be Grangemouth refinery as a share of Falkirk's emissions, or Alstom in Derby, or similar. Local indicators could help create stronger cost-benefit cases for investment in public health, or local investment in mitigation.
- Farmers may be required to measure ammonia emissions in future, but at the moment it can be difficult to determine which farm produces an emission once it is in the

atmosphere, and there are no agriculture-specific hand-held monitors. A place-based indicator for agricultural pollutants could form the basis for a new solution offering that level of detail, or prompt the creation of a new device.

This would also chime with a global surge of interest in supporting city-level actions to solve global problems like climate change, spawning a growing literature on sustainable development goals (SDG) "localisation".

> There are a lot of technologies developed by small businesses that are never put to use. If there was an interest in one of these technologies, small businesses would struggle to deliver in high capacities. Their technologies need to be trialled, scaled and licensed to other people to produce"
>
> Interview participant

4/ Help innovators find customers through test-beds, living labs, and building SBRI-style initiatives

Achieving environmental goals will likely only be possible through technologies that have not yet reached commercial markets.[32] There is also evidence from a range of contexts that commercialisation is a key challenge for environmental technologies, and technology-push funding can increase patenting but not business growth.[33]

Clean Air Tech in the UK fits this picture. It does have needs in more fundamental development of technology, but the major gap is still helping innovators find ways to bring their technologies to market. In particular, this challenge is acute for outdoor clean air suppliers whose primary customer is the public sector.

This means that innovation approaches should concentrate not just on improving the technological maturity of a solution - but also build the readiness of customers to buy and raise the profile of clean air. Aside from upscaling existing workstreams, this could include:

- **Test beds and demonstrators** act as facilitated demonstration sites for new innovation trials and pilots. Several test beds and demonstrations exist across the UK related to air quality. In recent years, The European Regional Development Fund facilitated two test bed demonstrations related to air quality in London – Croydon's IoT Air Quality Monitoring and London's First Clean Air Station in Marylebone.[34]

  In Croydon, AirPublic air quality sensors were deployed across a number of key construction sites in Croydon town centre to provide insights on sustainable construction measures in London.[35] In Marylebone, three large companies installed Airlabs dual filter systems inside of railway station advertising stands in a bid to create clean pockets of air in urban centres.[36] Smaller, localised demonstrations like these are effective in providing businesses, like AirPublic and Airlabs, with opportunities to trial their products, expand their networks, and exchange knowledge on solutions to tackle air pollution in the UK.

  Evidence from other government test beds, such as the DCMS 5G Testbeds, suggests that the technology readiness level (TRL)of most participants increased through this kind of programme.[37] Given that tackling air pollution is a shared priority between

multiple governmental departments, it seems fit for a large-scale test bed.

- **Living labs are also useful ways to develop opportunities for SMEs to trial their technologies.** Universities host living labs to foster real-life testing and experimentation environments among academia, government, industry and the public. The University of Leeds hosts the Leeds Living Lab, including The Air Quality Living Lab. This aims to better understand air quality issues on the University's campus, trials air quality innovation and solutions, and engages in citizens science research across stakeholders, from professors to students. It has expanded since 2017 to explore city-wide levels of air pollution from commuter exposure to indoor air quality. It boasts cross-discipline support from climate and atmospheric science, transport and engineering and more.[38] A similar approach could easily be taken elsewhere, or adapted to focus on specific sector challenges, or indoor air quality.

- **Creating a designated test bed city on the topic of air quality research and innovation.** The idea of an eco-city test bed is to consolidate innovation, products and services around a specific topic to one geographical region or area. In Sweden, for example, Helsingborg has been established as a city-wide test bed for exploring smart solutions.[39]

  Particularly in London, there is already mature collaboration between public authorities and third sector organisations on clean air. One high-profile way of demonstrating the potential of clean air – and galvanising public and private organisations around a clear challenge – would be to work with local partners to **establish London as the world's first Clean Air Tech test bed city.**

- Establish a **Clean Air Catapult** within the current Catapult Network. Catapults were established to help innovation get through the valley of death. They have also been successful in helping create cohesive sectors in areas of emerging technology. A good example of this was Future Cities Catapult's (now Connected Places Catapult) support for and development of the PlanTech Sector as part of its programme to innovate and digitise the planning process.

- Clean air projects could consider the **Small Business Research Initiative** (**SBRI**). This is a programme delivered by Innovate UK. It allows public bodies to acquire research and development services from providers who compete to develop solutions to defined problems. This improves public-private collaboration, helps smaller firms and non-profit organisations share in public R&D, and develops solutions tailored to public sector challenges.

> Monitoring has become a financial opportunity for entrepreneurs that might not prioritise environmental issues."
>
> Interview participant

5/ Focus innovation funding on high-end applications, particularly mitigation, analysis and sector-specific applications

There are many opportunities to improve basic monitoring technology, given the variable quality of products. However the basic technology is common. If standards are produced which improve the reliability of monitoring devices and create basic technical standards (which is recommended) then an effective floor to the market is created. Most likely, this means that monitoring hardware will become standardised, and mass-produced – at least in the largest markets of general outdoor and indoor air quality monitoring.

The UK's biggest opportunity is likely not to be in the mass manufacture of this kind of basic technology. **Instead, the most likely future is to develop a high-technology sector with strong IP, focussed on developing clear niches and applications**. This could include monitoring tools which go beyond the basic kit in terms of the quality, range and useability of the data. It will include developing hardware suitable for particular contexts or settings with unique needs. It will also include systems, both technological and operational, which mitigate, analyse and avoid pollution, such as software and modelling approaches.

As a broad principle, **Innovate UK's funding should reflect this priority: the UK's Clean Air Tech sector should be built on high quality, advanced applications, working from a strong original research base.**

> Clean Air Tech is very profitable. The value of the Tech is massive but there is still limited interest from industry."
>
> Interview participant

6/ Create scale for more mature technologies

At the same time, many proven technologies struggle to reach scale because their customer base of UK public authorities is small and fragmented: they might pick up a handful of contracts with local authorities, but struggle to get to a broader client base because councils are generally slow, risk-averse, and may require different pricing models. Some UK councils also struggle to win investment, even where there is a clear proposition to investors, because they are simply not big enough to gain the interest of pension funds, sovereign wealth funds, and similar large, patient investors.

This is a gap, and an opportunity. There is potential to use existing attempts to scale-up net zero procurement and innovation – such as the Core Cities Group's investor proposition developed for COP26 – and **create large-scale combined contracts (or innovation projects) for multiple places using the same technology.** This would allow more mature technologies to scale up, and for places would mean a viable scale to start interesting institutional investors.

This mimics the approach taken in the US to develop clean air in an indoor setting: the US Department of Energy worked with industry to design strict technical standards for high-efficiency air conditioning units for commercial buildings. They then organised a group of companies with large commercial real estate portfolios such as Walmart and McDonalds to engage in an Advanced Rooftop Unit Challenge – effectively creating a new market by using the convening power of government.

> We need an initative that brings like-minded people together that are dedicated to solving the problem. This is where Innovate UK could make a big difference. They could bring businesses together from previous projects to ignite innovation."
>
> Interview participant

7/ Focus on knowledge transfer, building networks, and raising profile

As part of the SPF, Innovate UK plays a role in raising the profile of innovation and commercialisation funding that could otherwise be lost in a heavily research-focussed agenda. The interview programme revealed that communication and knowledge transfer will play an important role in the next three years of the SPF. Innovate UK should capitalise on these priorities as it relates to enhancing innovation. Communication and knowledge transfer will be key for expanding the evidence base and cross-discipline collaboration that supports the Clean Air Tech sector.

Innovate UK should bring together its 'cohort' of businesses it has previously supported. With shared experiences entering innovation challenges, applying for smart awards and trailing their products, even those with completely different products will be able to connect on some levels.

RECOMMENDATIONS FOR GOVERNMENT

Leadership in defining the Clean Air Tech sector ultimately comes down to strong and clear messaging from the government, translated into visible action.

> There is a huge responsibility on the government to tackle air pollution and to hold polluting companies and industires accountable."
>
> Interview participant

1/ Visible leadership from government

This research identified that the sector has a clear view of the government's role in supporting its growth: **without public leadership, the sector will underperform**.

This is due to the nature of clean air itself and the structure of the sector. The market in solutions to monitor, mitigate and reduce pollution only exists due to legislation. Public funding is the major source of income for researchers. Sub-sectors include those dominated by public bodies, such as the NHS in healthcare. Regulation and standard-setting by government is not seen as a threat, but is actively welcomed - and unlike some sectors, this view is shared by both mature companies and new innovators.

Given these dynamics, there is a central role for government as a funder, coordinator and leader of the clean air tech sector. Clean air is a public good. Those working in the sector towards a future with cleaner air and a healthier public need to see that it is also a national priority.

> It is not about trying to solve the entire problem but identifying who needs to be influenced and how – what messages and channels need to be used to engage effectively with different groups."
>
> Interview participant

2/ Define and disseminate strong, clear messaging on air quality

Stakeholders identified that strong, clear and consistent messaging from the government on air quality is one of the most important elements in supporting the sector. There is a perception that this has been lacking: either due to insufficient investment, or a range of voices from government, or confusing language and messaging.

There should be a single communications strategy for clean air, with buy-in from all relevant departments including Defra, DHSC, BEIS, DfT, Met Office, Royal College of Physicians and more. This should outline key messages on the importance of tackling air pollution, contributing factors to the problem and an urgency for action. This could form the basis of a wider public information campaign in the future – but **the first step is clarity of thought, language and messaging from the government**.

> Defra treats air pollution as an environmental issue rather than a health issue. DHSC doesn't really focus on it at all, although some suggest that it should sit entirely under DHSC. Really, everyone should be thinking about it as cross-department."
>
> Interview participant

3/ Create a new public body

The central challenge for the Clean Air Tech sector is its fragmentation: it has lots of small parts which lack a sense of common identity, the ability to share knowledge, and to create new combinations of innovation between different organisations. This creates a **pressing need for a body or intermediary to provide leadership, direction, coordination and regulation on the Clean Air Tech sector**.

This research concluded that given the need to bring together different aspects of clean air a public body, or at least a publicly-led body, is needed. In particular, the understanding that regulation, funding and private innovation are all interlinked suggested that a body that can work within Whitehall and between departments is necessary.

Existing forums are well-regarded but are either too concentrated on research, or lack the ability to make different parts of government speak to each other. The gap is an institution that sits between departments, between public and private, between research and policy – and has the trust and institutional heft to make all of those aspects of the sector work more coherently together.

There are a range of options for a public body. According to the Cabinet Office, a 'public body' is a formally established organisation that is at least partially funded by the public to deliver a public or government service.[40] It is not a ministerial department, such as Defra or DHSC. It can be an Office or Team sitting between departments, such as the Office for Zero Emissions Vehicles which is shared between BEIS and DfT. It can also be a charity, subject to the terms of charitable purpose and charity law.

The exact form of body should be subject to further development. To support this recommendation, the initial questions on setting up public bodies from the Cabinet Office Public Bodies Handbook – Part 1 have been answered on the next page, to demonstrate that there is a clear and pressing requirement for the sector, a clear need for the state to provision the function or service through a public body, and no viable alternative.

Initial Questions on Setting up Public Bodies Applied to the Clean Air Tech Sector

01

Is the proposed public or government service or function really needed, and should it be provided by the state?

A private body would likely be dominated by longer-established companies with the capacity to contribute – when the problem here is the lack of a unifying home for both established actors, newer innovators, researchers, and the public organisations creating regulation and standards which shape activity in the sector. Within central government, Clean Air Tech is an inter-departmental problem. Cooperation often relies on individual relationships and networks. The Clean Air Tech sector is different from other sectors in that in practice it is applicable to everyone – across industries, disciplines and sectors – as air pollution is an issue that could impact the entire UK population.

In the US and the EU, environmental protection agencies are responsible for addressing and tackling air pollution. The function of these agencies is to address environmental health concerns including how they impact human health. While Defra does this to some extent, the impact that air pollution has on human health is not fully known or connected in practice. Several stakeholders in this research identified that the UK's air pollution portfolio could sit under the DHSC. The risk of silo-ing air pollution into either Defra or DHSC is that necessary overlaps and co-benefits between environmental and human health could be missed. Thus, there is a need to for an intermediary public body to unite the innovation and solutions that are emerging in this space.

02

Is there sufficient demand for this, and does it contribute to Government policy, commitment or legal obligation?

The technology that exists to tackle air pollution relies heavily on governmental regulations and policies. Legislative frameworks on air quality limits and emissions standards guide the demand for research and development of Clean Air Tech. There is a significant demand for the UK to advance its ability to position itself in the global Clean Air Tech market.

At present, it is restrained by a lack of standardisation or certification process to ensure high-quality and effective innovations are those that entering national and global markets. A public body would set these standards for Clean Air Tech, enforce them, accredit innovations and engage researchers and innovators across departments and disciplines.

03

Is it unique or something sufficiently similar already being provided elsewhere?

A public body would not only function to bring together environmental and human health while tackling air pollution but it would facilitate communication, knowledge-transfer and a community that enables a cohesive Clean Air Tech sector. At present, it is not something sufficiently similar being provided elsewhere. This is not something that can be done by the new Office of Environmental Protection (in 2021 as part of the Environment Act), which primarily is designed to evaluate broader environmental health assessments and practices that exist in the UK.

While a Clean Air Tech public body could perform these tasks as they relate to air quality needs assessments, it is evident that there is a wider need for a public body that support innovation and drives investment in this field. On a global scale, the UK would be the first country to establish a Clean Air Tech body, setting an example to the world that it is a national priority.

04

Will this entity operate commercially, covering over 50% of its cost from commercial activities?

A new Clean Air Tech public body would be unlikely to operate on a commercial basis. Some funding could be recovered from membership fees or event fees – but given the need to include start-up and early-stage companies, as well as research institutions without large discretionary budgets, this is unlikely to be 50% of costs.

05

Should the function be provided by Government, Parliament, Local Government or Devolved Administration?

Clean air legislation is a reserved matter. Public services are generally devolved but elements of public health are reserved, and coordinated on a UK-wide basis. Given the link to wider government policy – and that this is not a parliamentary or scrutiny need – a government body is appropriate.

> There is a clear adoption of new technologies at the commercial level but the lack of regulations and certifications has slowed its adoption into policy. There are gaps in data that could have ultimately helped to save lives."
>
> Survey respondent

4/ Strengthen and clarify legislative frameworks on air quality

Leadership from government on air quality is needed to ensure that tackling air pollution is seen as a national priority. The UK faces a critical moment in time to **clarify its legislative frameworks on air quality**.

Before Brexit, most environmental policy and laws in the UK were enforced by the EU, including legal action against the UK for failing to meet air quality standards. The Environment Act 2021 outlines the UK's environmental policy, laws and targets for addressing environmental protection concerns in place of those previously enforced – meaning that the next two years are a critical period for defining implementation of these goals.

Specific ways to focus air quality legislation would include:

- **Ensuring that post-Brexit commitments are maintained or strengthened.** There are opportunities for the UK to demonstrate a leading stance on tackling air pollution by adopting the WHO's Global Air Quality Guidelines (AQGs) that were updated in 2021 and are currently under revision to be adopted by the EU. The ability to clarify legislative frameworks also provides the UK the flexibility to include human health elements to its environmental protection strategies, including those related to tackling air pollution.

  On the other hand, there are concerns that if the UK does not strengthen legislative frameworks on air quality and tighten legal limits of air pollutants, the UK will fall behind in meeting net zero targets by 2030. This poses a risk to the health of the public given that WHO's AQGs were also specifically developed to get countries to levels of air quality that protect public health.

- **Ensure that overall goals are aligned with product-specific regulations.** Overarching air quality targets sit alongside legislative frameworks which are focussed on individual pollutants, and sometimes individual industries or sources of pollution. For example, all local authorities have air quality goals and for most, road transport is a major contributor; but legal limits on pollutants are set for individual vehicles, and often at a level that is far looser than wider air-quality goals. This means many places have strict air quality goals, but have a mix of vehicles which are legal and they cannot influence. This kind of big-picture and sector-focussed regulation needs to be aligned.

- **Ensuring enforcement.** The UK's air quality targets are generally in line with other developed countries. Achieving them is crucial for the credibility of government's wider environmental approach – but it is also important for growing the market. The Clean Air Tech sector will thrive only if it is clear that the UK is committed not just to ambitious targets, but adopting the technologies, innovations and policies needed to make it happen.

5/ Establish standards for Clean Air Tech

In the Clean Air Tech sector, documentary standards are needed to set out process for taking air quality measurements, and air quality standards establish which pollutants are "good and bad", what their limits should be and fines for breaching those limits. These are standards established by the government from which industry can currently invest, innovate and commercialise Clean Air Tech products and services. However, this research identified a unanimous concern for the lack of standards that exist that certify these products and services.

Although the UK is no longer a part of the EU, it is still a part of SEN and ISO standards – these standards are slow and complex. Products and services can also receive an MCERTS approval, however this certification is not specific to Clean Air Tech. **The government should urgently seek to establish a process for businesses to certify their innovations and solutions.** This would not only act as an accreditation for high-quality products and services in the UK, but make it easier for consumers and the public to understand the market.

A **Publicly Available Specification** (**PAS**) would be an appropriate first step towards ensuring that there is a quick public standard for industry to follow.

> "The MCERTS scheme is non-functional. There is no way to certify products effectively in the UK. Product test is done in Germany to be competitive globally and regulations are complaints driven rather than authority driven."
>
> Survey respondent

> "Third party sensor networks are being used to support local authorities – the challenge with these is that they vary in quality of sensors, data processing and reporting. PAS could allow for private companies to set up standardised sensor networks that support local authorities and provide transparent public engagement."
>
> Interview participant

> Clean air is part of what our tech does [a last mile delivery service].
>
> It is a more efficient and cheaper way of transporting goods that reduces carbon and air pollution. However, traditionally refrigerated vehicles with heavy diesel enginges are cheaper and unregulated by the EU. New policies and regulations in the UK would actually help our business to grow."
>
> Interview participant

6/ Pursue complementary policies

Several stakeholders in the interview programme identified specific policies that would support their ability to effectively tackle air pollution in their fields. These would include policies that tackle car culture and improve public transport, or public health policies that encourage local authorities to tackle conditions derived from lifestyles and environmental factors. These policies not only support clean air – they also create sub-markets for Clean Air Tech which serve these niches. This means that they should be seen as indirect support for the Clean Air Tech sector, and encouraged on that basis.

RECOMMENDATIONS FOR INDUSTRY

> Clean air tech is an untapped market. As more research is done and sheds light on new hazards, new technology will be needed. It all comes down to the way that we silo our concerns. The animal industry is looking for ways to monitor animal diseases but animal and human health are viewed separately. There is a movement to look for synergies between how we look after the environment and ourselves."
>
> Interview participant

Industry itself should reflect on the current state of the Clean Air Tech sector and how it needs to function going forward to effectively meet the environmental and health needs of the UK.

1/ Pay attention to market gaps

Stakeholders in academia and government expressed a belief that the private sector can be slow to identify gaps in the market. This is seen as lacking awareness and information to understand gaps, not a challenge with technology or developing a sustainable business model to serve those gaps. As a general principle, private suppliers should try and build stronger networks to help identify these opportunities – several are highlighted below:

- **There is a specific need for monitors and sensors for emerging harmful air pollutants.** The market for indoor air pollution, ammonia emissions, animal diseases and micro and nano-plastics is under-served. Although the evidence base on these air pollutants is still growing, there is an opportunity for businesses to bring new innovations to bear on these emerging challenges.

- **There are emerging fields in air quality research that would benefit from investment from industry to be fully understood.** The existing evidence base on outdoor air pollution is strong, while the components and impacts of indoor air pollution are still being understood. Equally, the outdoor-indoor continuum, relationships between environmental and human health, and impacts that net-zero strategies have on air quality are gaining traction. Academic air quality research vastly outweighs partnerships between businesses and researchers (in line with the UK's wider R&D patterns). This creates a range of knowledge gaps and areas of emerging interest which businesses are well-placed to fill. Investment from industry could enhance the evidence base that exists in the UK on air pollution which drives innovation in the UK for unique, leading technology, products and services.

- **There is clear demand for technology that targets emissions at the source.** Stakeholders engaged in this research identified that the largest commercial opportunities are in emissions control at the source. Almost every piece of mechanical engineering produces emissions and each product could have their own technology applied to it. This is a vastly underutilised market for Clean Air Tech. There is a significant gap between the potential of this field, and existing supply.

- **There are products and services in the global Clean Air Tech market that could benefit unmet business and societal needs in the UK.** Several products and services were identified in this research that exist in global Clean Air Tech markets that are currently unregulated in the UK and thus cannot enter the UK's Clean Air Tech market. For example, a slurry management technology which uses a novel type of floorboard to increase the nutrient value of slurry and decrease ammonia emissions in the agricultural sector. Established UK suppliers could be more systematic in investigating products and services that exist in global markets and how they could be translated to fit the regulations in the UK.

2/ Ensure quality over quantity

The interview programme suggested that the air quality monitoring and sensing market is oversaturated. On a consumer level, identifying the best kit to use is confusing. The vast majority of low-cost sensors need reference checks in order to be effective.

Funding high quality continuous monitoring is also challenging for local authorities – diffusion tubes are cheaper but reliably inaccurate. Particulate matter is harder to measure and passive monitoring is not accurate enough to provide results on its distribution. Additionally, low-cost sensors can range from £15-500k and vary significantly in quality.

There is an opportunity for the **industry to bridge the gap between the highest-quality, expensive and non-mobile monitoring stations and the lowest-quality, inexpensive and inaccurate sensors.** This could mean offering comprehensive continuous data monitoring package, which would save consumers time in having to learn how to use new pieces of kit and manipulate data to fit their needs. Businesses could also focus on producing new high-quality monitors that target one specific air pollutant, rather than producing a product that is low-quality for several air pollutants or includes the same patented technology as existing products.

The wider principle is that the UK's main strengths are likely to lie in higher-end design, IP, and in creating new business models. Sensors themselves increasingly represent a mass-produced commoditised market. As a rule, the UK's footprint of existing researchers and companies suggests a future which is about higher-value packaging of that equipment, and seeking intelligent ways to avoid pollutants in the first place.

> There are two types of Clean Air Tech providers: sensor innovators that produce new technologies and system packaging innovators that package existing technology to meet user needs more directly. There are varying levels of maturity and Technology Readiness Levels (TRLs) between the two groups."
>
> Interview participant

> It's a bit of a Wild West in how companies are using sensors to produce data at present. This can make commercialistation easier – it's largely a marketing challenge to deliver growth. Academics and researchers who are focused on solutions are not as good at selling themselves even though their ideas might be better."
>
> Interview participant

> What ever happened to the producer pays principle? Those that can't afford clean air tech will suffer disproportionately."
>
> Interview participant

3/ Invest in quick-win solutions and innovations

Across the board, there are businesses and organisations with strong sustainability ambitions and clear agendas to protect the occupational health of their employees. **This research identified that industry could invest in quick-win solutions and innovations with partners that are willing to trial their technologies – some sectors could be more willing than others to participate, but it is worth exploring and networking to identify where these solutions and innovations could take place.**

A short-list of topics identified are:

- Hand-held ammonia monitors for farmers
- Grid smart cities apps applied to freight
- Consolidation hubs applied to transport, freight and aviation
- Digital twins applied to city-level modelling of air quality
- Open access data portals for local, regional and national air quality data applied to public engagement
- Consolidating air quality data from multiple vendors applied to industrial sites and power plants

4/ Embed social principles during development stages

Poor air quality interacts with and deepens existing inequalities. Disadvantaged groups often face greater exposure to air pollution due to their geographical location. Environmental quality tends to be significantly worse in poorer neighbourhoods. Often these communities have less green space, a greater concentration of major road links and are closer to industrial operations. Conversely, socio-economically disadvantaged individuals often contribute the least to air pollution due to reduced rates of car ownership.[39]

Increased exposure means that these marginalised communities face a greater risk of suffering negative health consequences. However, due to facing economic disadvantage, these individuals and communities are often unable to purchase clean air technologies to improve their living conditions. Furthermore, questions exist regarding whether these individuals should have to face this financial burden when they are not responsible for the pollution. System-level factors need to be considered to ensure that air pollution is tackled in an equitable way.

This kind of thinking is increasingly common in public buyers of clean air technology, particularly in public health in the UK, but also in emerging markets. Both to fully exploit the commercial opportunity – and to create an industry which genuinely drives progress – businesses should embed the language and mindset of social justice.

> Clean air tech should involve community research specialists more in the field – co-creating research methods will ensure that technology is delivered in an equitable way."
>
> Interview participant

5/ Involve community research specialists

There seems to be a disconnect between communities and the clean air tech sector. Currently, it is rare for research and industry to engage with affected communities. This means that the technologies being produced often do not reflect their priorities or address their needs.

The clean air sector must take a more collaborative, integrated, and multidisciplinary approach. Community research specialists should be involved in research, design and production of clean air technology. This would allow technological innovation to better address the needs of vulnerable communities facing air quality issues and catalyse progress towards producing a more equitable environmental and health landscape.

RECOMMENDATIONS FOR HEALTH PROFESSIONALS

> We're not very good at joining the dots between clean air tech and the health and social benefits that we will get out of using and upscaling them. We need to show that technology can make the world a better place – they are not just designed to meet regulations, there are social benefits as well."
>
> Interview participant

Health professionals play a major role in delivering accurate and trustworthy messaging on Clean Air Tech.

1/ Get more involved

Alongside government, health professionals play a leading role in ensuring messaging on air quality is translated to the public. Health professionals work on sensitive aspects of people's lives – their health and well-being. This means that the public often sees health professionals as trusted members of society. They may be more willing to engage on conversations about air quality with health professionals rather than the government.

It is critical that health professionals get more involved in the Clean Air Tech sector to increase the awareness of air quality concerns, research and innovation to their patients, and ensure that Clean Air Tech is meeting unmet health and social needs. They should act as an intermediary between their patients and industry, as industry often misses community-level engagement in their development stages.

Engaging with the Clean Air Tech industry is also important because there will be aspects of products and services that are unable to meet the needs of health professionals in ways that they are intended to. Increased engagement with businesses will enable innovators to meet market gaps more effectively.

For example, there is a limited understanding of the toxicity levels of harmful air pollutants and how these levels impact human health. Most technology, products and services currently interpret the mass of PM2.5 particles and assume that PM2.5 presents itself in a single way. The WHO and Global Burden of Disease project currently captures health risks of air pollution in one 'exposure-response' function- the likelihood of someone that has inhaled a certain mass of PM2.5 dying from a related disease. This needs to be further explored in research alongside of health professionals. **Health professionals should get more involved in how data on air quality and health are presented.**

> No I don't think that most GPs think about air pollution when making diagnoses - it didn't come up in medical school."
>
> Interview participant

2/ Formalise education and training

In order for health professionals to effectively champion the Clean Air Tech sector, there needs to **be formal education and training within the NHS and across health and social care on air pollution and how to respond to it.**

This research identified a significant lack of awareness and formal education and training for GPs, and other health and welfare services, in the UK on environmental health, specifically air pollution. This can be detrimental to patient health and fails to meet societal need for increased understanding and messaging on air quality, which will subsequently increase demand for Clean Air Tech.

In the wake of the coroner's case of Ella Adoo-Kissi-Debrah, the Royal College of Pharmacy set out ambitions to include material on air pollution in its training. Although some universities offer elective modules on environmental health where topics of air pollution would be taught, it is unclear what level of formal education and training is currently provided to medical professionals in the UK.

In 2020, Global Action Plan put a call out for a cohort of 40 GPs across the UK to become Clean Air Champions in a three-month pilot to better understand ways to engage with patients on topics on air pollution related to human health. This project was supported by Defra and implemented by Global Action Plan and UKHACC and Imperial College London.[42] Results from this initiative were clear – current medical training and GP materials regarding patient advice on air pollution are insufficient. **Royal Colleges, universities and NHS education authorities need to improve focussed education on clean air, particularly at postgraduate GP level.**

There are a variety of ways that health professionals should get involved today should their Universities not provide them with formal education and training during their degrees:

- Health professionals should take it upon themselves to learn how environmental conditions could be impacting patient health. This is especially important for patients with chronic diseases, such as asthma, COPD and cardiovascular diseases. Preventative treatments may be applied for certain patients relating to emissions exposure or short and long-term environmental conditions.

- The Clean Air Hospital Framework developed by Global Action Plan with Great Ormond Street Hospital in London, is publicly available for health professionals to set professional ambitions for themselves and their workplace on tackling air pollution related to travel, procurement and supply chain, construction, energy, local air quality, communication and training, and hospital outreach and leadership. This framework has been created by Great Ormond Street Hospital which since included air quality components in building development plans. Health professionals at the hospital are practicing patient-engaged research and campaigns to encourage conversations on clean air – including clean air superheroes and a Young People's Forum.[43]

> We need to start thinking about what interventions and solutions can be put in place as we raise awareness on local air quality issues."

Interview participant

3/ Embed procedures within health and social care systems

Alongside formal education to raise awareness and understanding of the risks of air pollution amongst health and care professionals, procedures must be put in place to deal with air quality related illnesses effectively.

The recent case of Awaab Ishak highlights failings within health, welfare and housing teams to adequately respond to air quality related health risks. In December 2020, a two-year-old child, Awaab Ishak, died from a respiratory condition caused by exposure to mould in his home in Rochdale.

Awaab's family had repeatedly raised concern around their living conditions with their housing provider and health professionals, however action was never taken. The guidance of their housing provider was that the mould should be painted over. When Awaab was admitted to Rochdale Urgent Care Centre suffering from shortness of breath, he was later discharged to return to his home, the ultimate cause of his problem. Despite increasing concerns around the family's health, they were forced to continue living in a poorly ventilated and mouldy property.

Multiple organisations and agencies failed to take a proactive approach despite evidence of a risk to human health. In September 2020, a community midwife had completed a special circumstances form to children's services to highlight concerns about the mould, however this was not shared with the GP or health visitor, and there was no evidence that action had been taken following this expression of concern.[44]

Clear pathways and procedures must be put in place to deal with occurrences such as this case more effectively and prevent unnecessary illness and mortality. Several opportunities for intervention and escalation were missed in Awaab's case. As recognition of the role of air quality in health grows, formal practices must be developed and utilised.

APPENDICES

APPENDIX I

PROJECT METHODOLOGY

A five-phased approach

Phase 1

Aims	To clarify the objectives, definitions and processes involved in the project.
Activities	Detailed scope of project; clear agreement on purpose; shape and scope of the project; a working definition of 'Clean Air Tech'; initial stakeholder list; draft report outline.
Outputs	Defining 'Clean Air Tech'; discussions on project scope, stakeholder mapping; early phase development of metrics and international benchmarking; SWOT analysis development.

Phase 2

Aims	To establish broad outlines of the sector, alongside potential future growth.
Activities	Literature and policy review addressing the size, scope and scale of the sector; policy landscape review to understand legislation on health, environmental protection and emissions; baseline lists of market players and trends, elements and sub-sectors working in the sector.
Outputs	A systems map including themes in the sector, identification of prominent companies and information about them.

Phase 3

Aims	To explore the sector in more detail and provide a baseline of the main dynamics, range of players and outlines of the sector.
Activities	Interviews with companies identified by stakeholder mapping to explore trends and relationships in the sector; workshop with researchers and public authorities; workshop with internal stakeholders to sense-check findings and generate buy-in; international benchmarking to understand the maturity of the UK sector in relation to comparative countries; compiling and refining SWOT analysis.
Outputs	Detailed SWOT analysis of sector; development and verification of Phase 2 findings; clear understanding of the UK's performance and global opportunities.

Phase 4

Aims	To develop a plan based on the findings of previous phases to define how the sector can progress.
Activities	Mapping barriers and opportunities to the development of the sector; collaboratively developing actions with Innovate UK; refining actions and developing specific recommendations.
Outputs	Developed set of barriers and opportunities; a refined and detailed set of recommendations with an assessment of potential impact.

Phase 5

Aims	To produce and disseminate final outputs.
Activities	Drafting and finalising of final outputs including a report, a high-level summary and other briefings.
Outputs	Final report, high-level summary, additional briefings.

APPENDIX II

PROJECT FINDINGS

Interview Programme

In total, 41 stakeholders were interviewed from a range of organisation types, sizes and sectors.

The interviews were wide-ranging with the specific focus of the conversations varying depending on the organisation and the status of the research and discovery programme at that time.

The figure below shows the breakdown of stakeholders across academia, industry, the public sector and the third sector. Overall, a good representation was achieved across these sectors. Industry represented the largest proportion of stakeholders, with the third sector being the least engaged sector. This is due to the focus of this research being placed on the development and roll-out of clean air technology which is more closely associated to the work of private companies in this industry.

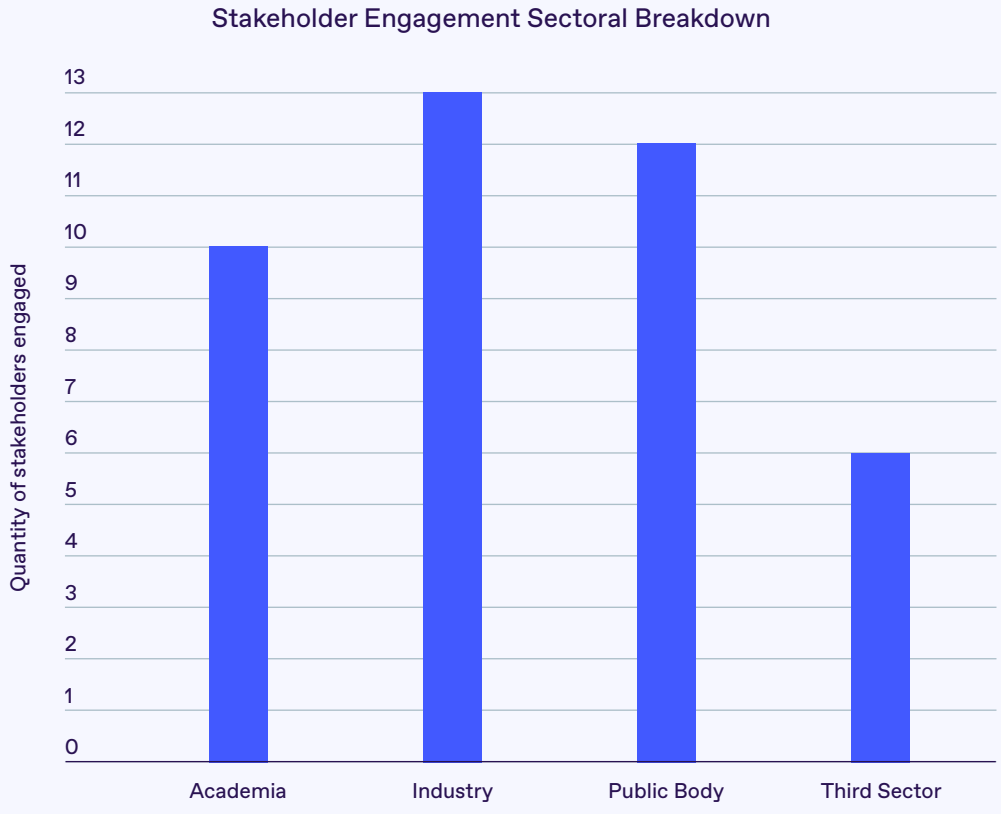


Table: Interview programme thematic analysis

KEY THEMES	Theme 1	The Clean Air Tech sector exists but it is not cohesive
	Theme 2	There is a need to understand the impacts of air quality on human health
	Theme 3	Current Clean Air Tech products and services are inadequate
	Theme 4	The sector needs a public body or intermediary
	Theme 5	There is a lack of public awareness on air quality and its impacts
	Theme 6	There is a lack of standardisation for Clean Air Tech
	Theme 7	The sector needs new policies and regulations from government to drive innovation
	Theme 8	Indoor air quality is a new field and less understood and regulated than outdoor air quality
	Theme 9	The sector needs cross-discipline collaboration
	Theme 10	There is a huge amount of opportunity for the Clean Air Tech sector to grow
	Theme 11	The sector needs to better the cobenefits that net zero strategies have on clean air, as well as the unintended consequences
	Theme 12	The sector needs better funding options and pathways to the market
	Theme 13	There is a general concern for the amount of air quality data being produced that is not reaching the public realm

Workshop

Stakeholder engagement included a workshop that brought together seven individuals working across government bodies, academia, industry and the third sector, sharing perspectives on the topic of Clean Air Technology.

Urban Foresight organised a Microsoft Teams meeting to conduct the workshop. Seven individuals attended with backgrounds reflecting both business needs and funding solutions. The purpose of the workshop was to bring together a group of stakeholders working on air quality research or technology to generate dialogue around the current shape of the sector.

The working definition of 'Clean Air Tech' was presented for feedback: **'Clean Air Tech' is defined as any application of technology that monitors or cleans the air, both indoor and outdoor, of harmful air pollutants through prevention, mitigation or control.**

Participants generally agreed that 'Clean Air Tech' is a product or service which can improve indoor or outdoor air quality and reduce the negative impacts of air pollution on health and well-being. This could be through reducing air pollution levels, enabling a reduction in exposure, or monitoring air quality.

Notably, participants felt that the definition may not implicitly suggest tackling emissions at source, which is a critical element of the sector – preventing harmful air pollutants from being emitted in the first place.

There was a consensus that there is less clarity around indoor air quality, as this is a newer, less regulated market. This can be difficult to model. Separating the indoor and outdoor aspects in the definition would reflect the differences in technology, sources of pollution and potential solutions, but the need for high-level awareness of the significant interaction between the two areas prevents the distinction from being refined further.

Depending on the scope of a particular product or service, the definition of what pollutants should be considered will vary. However, there is a danger that if the definition is too broad, it can be difficult to target interventions and funding. Urban Foresight included a list of relevant air pollutants with caveats representing actioned feedback both from the workshop and wider interview programme.

Urban Foresight also led a match-making activity to better understand the participants' needs and solutions in their areas of expertise and business. A summary of these needs and solutions are presented in the table on the next page.

Table: Results from workshop match-making activity. Key themes are in blue.

NEEDS	SOLUTIONS
Awareness: there is a general societal need to raise awareness on the dangers of air pollution on environment and human health.	Behaviour change: support population-level behaviour change to prevent air pollution and increase awareness of the dangers of air pollution on environmental and human health – education from a young age is a big part of this.
Clear routes to market: there is a business need for clearer access routes to entering the market, specifically for Clean Air Tech hardware, and an understanding of who these products are going to be sold to at scale.	Strong, clear messaging: implement strong, clear messaging from government so that the sector, and particularly the market, knows how to respond to the size of the challenge.
Clear fundings streams: there is sector need for regulated funding opportunities to drive the 'Clean Air Tech' sector – at the moment funding is sporadic.	Market pathways: implement clear market pathways to sustain funding needs in the sector and avoid the 'Valley of Death'.
Amplifying co-benefits: there is a pragmatic need to include cross-sector impacts in the 'Clean Air Tech' sector – i.e. net zero and climate agenda to include public health and clean air agendas – avoiding unintended consequences on each other.	Regulatory body for 'Clean Air Tech' solutions: a regulatory body for 'Clean Air Tech' that certifies tech to a certain standard would drive innovation within the sector.
Collaboration: there is a sector need to bring together the wide array of stakeholders that exist within the sector - a special interest group could keep relevant stakeholders informed of challenges and solutions.	Policy instruments: create new policy instruments that encourage innovation through knowledge-sharing, both nationally and internationally.
Indoor air quality research: There is a general research need to better understand indoor air quality which will drive the indoor air quality market, which is less evolved than the outdoor.	Access to data / solutions: a central repository / library for 'Clean Air Tech' solutions could allow local authorities, government, charities, etc. to see what's already been trialled and developed.
Visibility: there is a research and business need for novel 'Clean Air Tech' solutions to be implemented in public spaces.	Financial support / incentives: uptake in a structured financial support / incentives programme to support 'Clean Air Tech' – this could be something similar to Electric Vehicle charger subsidies.
Building equity into tech solution: there is a general social need to include the people who are most affected by air quality in decision-making, particularly those that are typically left out of tech solutions.	Diversity and inclusion: all stakeholders need to be involved in decision-making within the sector, particularly those most vulnerable to the impacts of air quality, with a focus on diversity to ensure that tech solutions benefit local at-risk communities.
Culture change: there is a societal need to encourage individuals and businesses to take responsibility for their impacts on air quality.	
Avoiding the 'Valley of Death': there is general need to address the gap between well-researched potential products and commercialisation opportunities.	

Survey

To support the findings of the interview programme, Urban Foresight administered a survey on behalf of Innovate UK.

The survey responses contribute to the evidence base to make the case for a well-supported and cohesive 'Clean Air Tech' sector, and to understand stakeholder views on the biggest opportunities for growing the sector in the UK.

Survey responses were used in accordance with GDPR for this research only. All data relating to employment and finances were aggregated, anonymously. The information reported do not reflect an individual company level.

The survey collected 146 responses. Respondents answered questions according to three categories:

- Demographics
- Market / sector
- Clean Air Tech

Demographics

The survey respondents were predominantly:

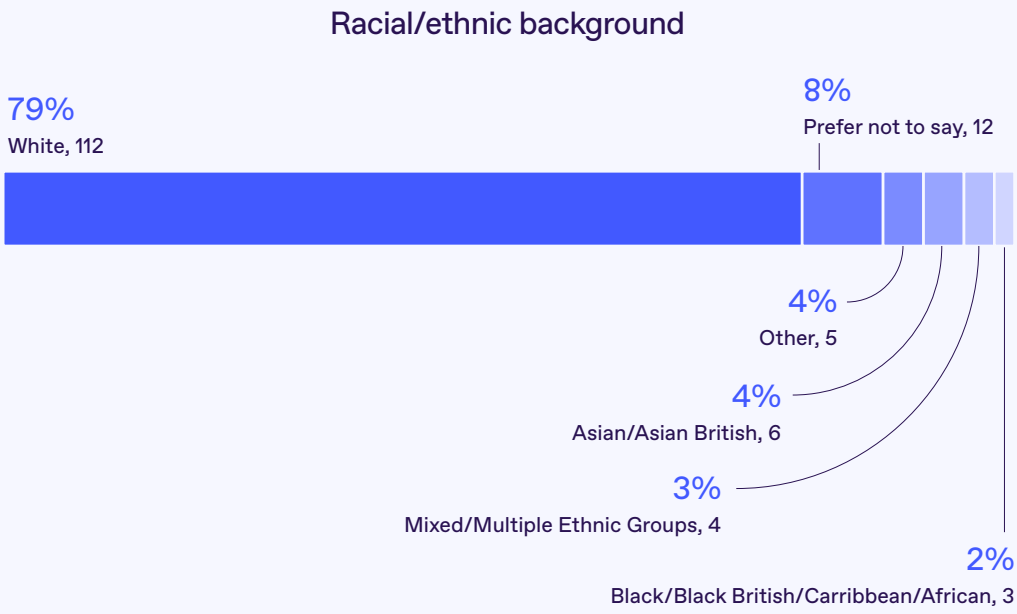
- White (79%)
- Male (85%)
- Holds a postgraduate degree or PhD (66%)
- Directors, CEOs and Founder (53%)

The survey indicates that there is some diversity in terms of ethnicity in the sector. Given that 97% of UK top firms have at least one ethnic minority on their board, and that UK STEM postgraduate courses do well to attract ethnic minorities, this diversity is to be expected.[47] However, all non-white respondents operate at Director or CEO level. This could indicate there is a lack of diversity beyond the Director level in the sector. Further, given just 15% of respondents are women, the survey data indicates that women may be significantly underrepresented in the sector.

The Clean Air Tech sector needs to include individuals of all socio-demographic backgrounds, racial / ethnic groups and educational attainment levels to adequately innovate solutions that address systemic causes of public health challenges caused by air pollution.

This can be done by:

- Focusing on narratives and lived experiences
- Cross-sector and discipline collaboration
- Community research specialists



Market/sector

The Clean Air Tech sector is not easily defined. 75% of our survey respondents were from the private sector, 25% from the public sector, 3% from the third sector and 4% other.

The survey indicated that 140 organisations reported total current employment of 92,969 and total turnover in excess of £1 billion. However, not all of these reported employees or this reported turnover can be wholly attributed to Clean Air Tech, particularly within large organisations. As such, further analysis on employment and turnover is confined to SMEs.

1. 113 SMEs in the Clean Air Tech sector reported a total of 1,609 employees and a combined turnover of between £81.5 million and £306.9 million.

2. The majority of SMEs (39%) reported turnover of £0-100k, with a further 30% reporting turnover of £100k-1m. However, 16% of SMEs reported turnover of £1m-2.5m, 13% reported turnover of £2.5m-10m, and 2% reported turnover of £10m-50m.

3. Projected employment growth over the next five years (to 2027) varied widely across the 113 SMEs that provided employment data, ranging from the 17% of SMEs which reported somewhat limited growth of 0-9% to the 33% who forecast growth in excess of 100%.

4. Aggregating across respondents, SME employment is projected to rise by between 425 (26%) and over 716 (44%) over the next five years (i.e., by 2027).

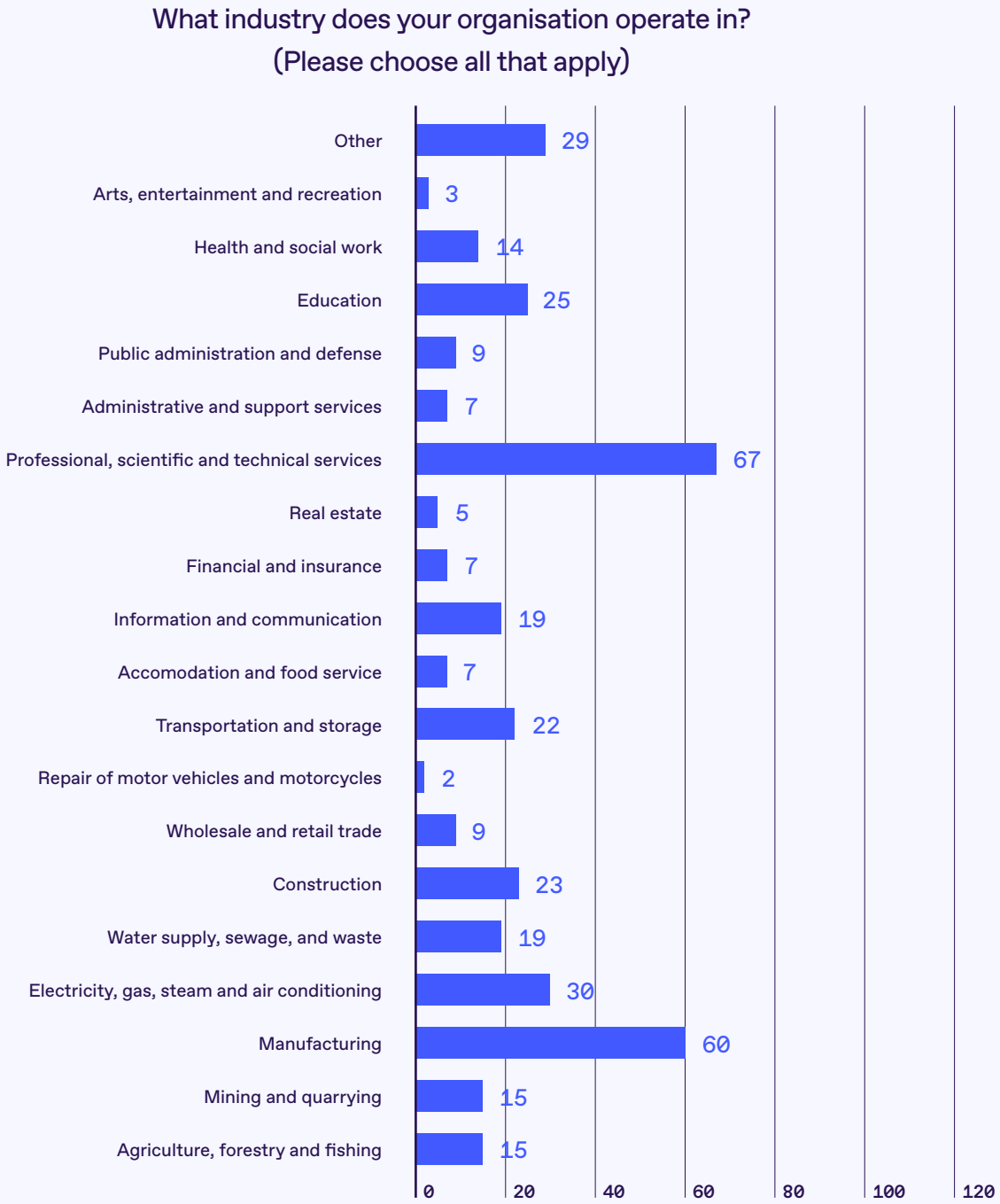
5. Although projected turnover growth over the next five years (to 2027) varied widely across the 112 SMEs that provided turnover data, the majority of organisations (47%) anticipated growth in excess of 100%.

6. Aggregating across respondents, SME turnover is projected to rise by between £35.3 million and over £174.3 million over the next five years (i.e., by 2027).

7. The primary location of the vast majority of SMEs (95%) was in the UK, with 88% located in England. However, more than half of SMEs (52%) reported that they operate or provide services outside of the UK.

6 industries stood out as being the most involved in the Clean Air Tech sector:

- Professional, scientific and technical
- Manufacturing
- Electricity, gas, steam and air conditioning
- Education
- Transportation and storage
- Construction



Clean Air Tech

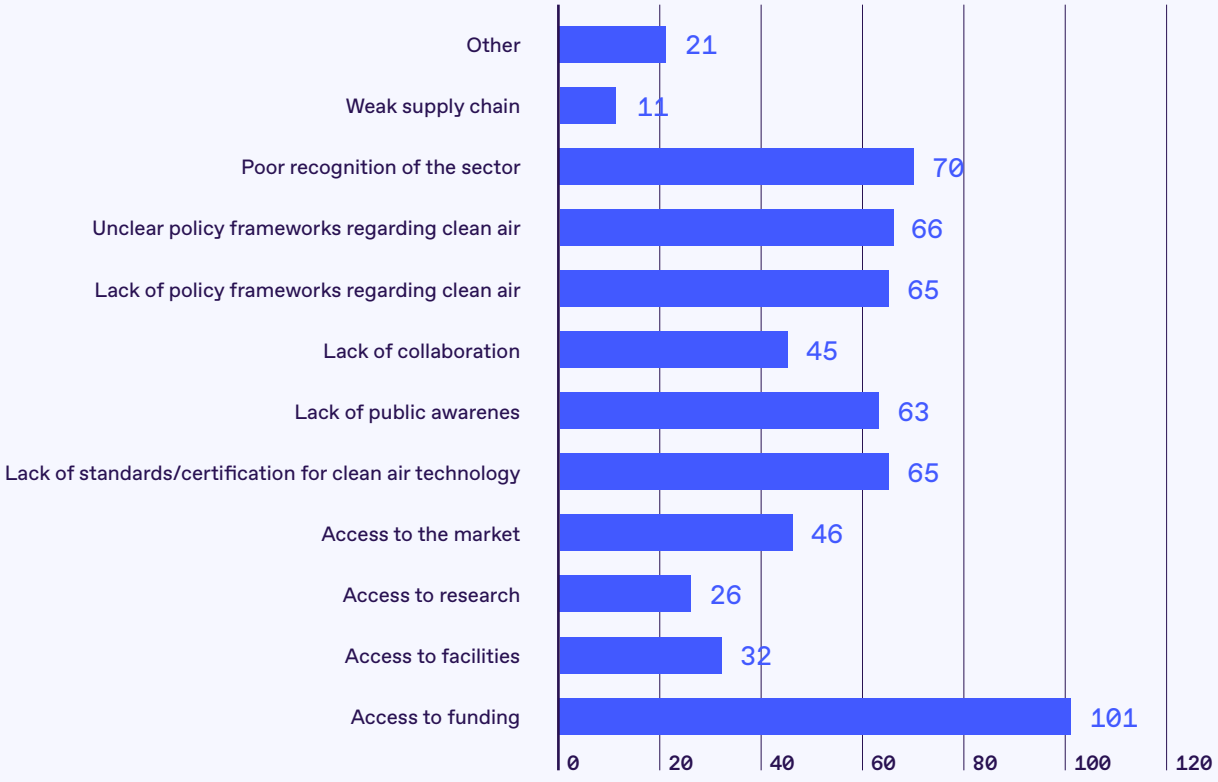
The Clean Air Tech sector exists in the UK. However, it does not function cohesively.

- 66% of survey respondents identified that the Clean Air Tech does not function well as a sector in the UK.
- 83% of survey respondents do consider themselves to be a part of the Clean Air Tech sector.

The survey identified key existing challenges for the sector, specifically:

- Access to funding
- Poor recognition of the sector
- Lack of / unclear policy frameworks
- Lack of public awareness
- Lack of standards / certifications for Clean Air Tech

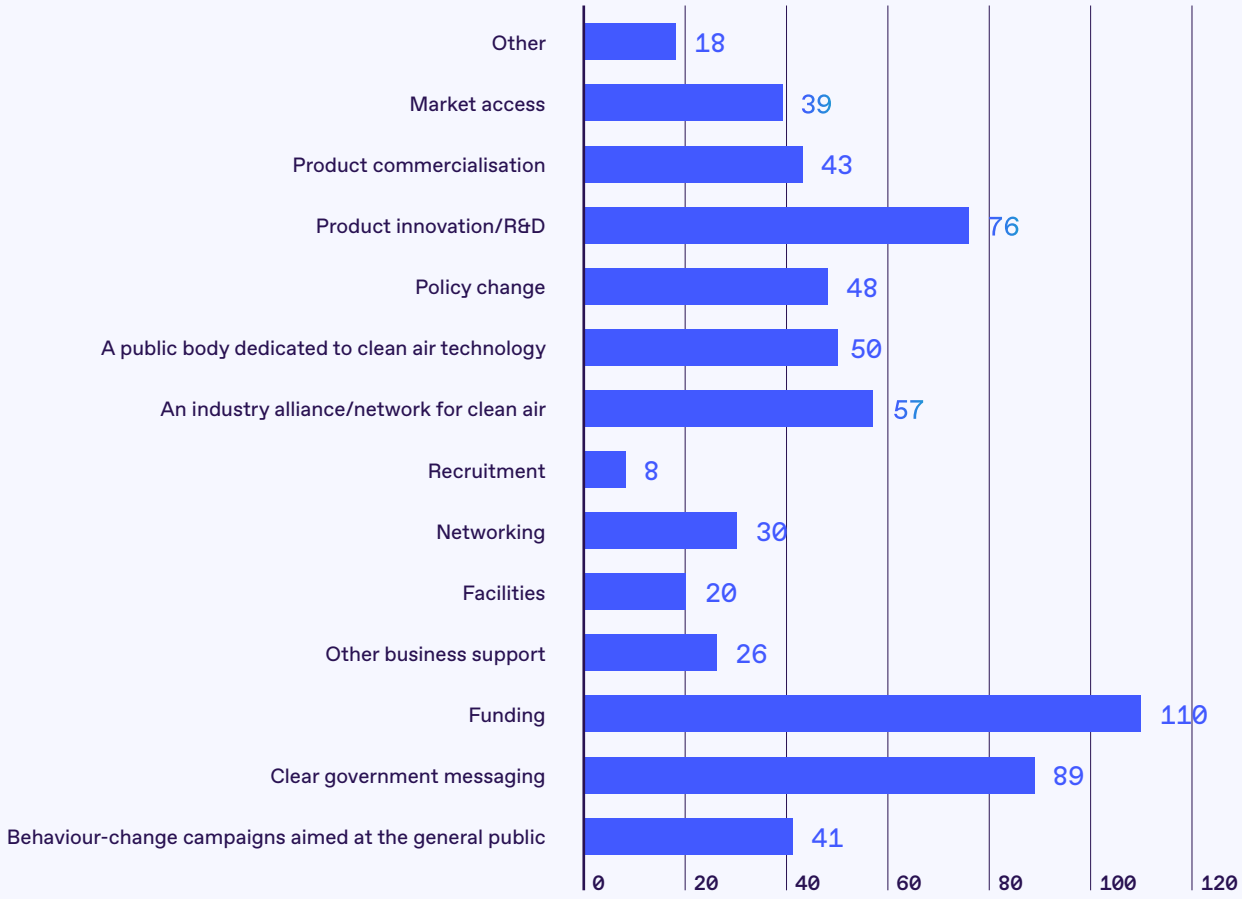
What do you see as the key existing challenges for your organisation in contributing to the 'Clean Air Technology' Sector (Please choose all that apply)



The survey identified that the sector needs support, specifically in regards to:

- Funding
- Clear government messaging
- Production innovation / R&D
- An industry alliance / network for
- A public body dedicated to clean air
- Policy change

What support would you like to see to help your organisation achieve its ambitions? (Please choose all that apply)



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