Department for Environment Food & Rural Affairs

Ricardo Energy & Environment

Innovative Technologies

Initial study findings and on-going work

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Study aims and scope

This work is being carried out as part of Defra's on-going work to:

> *Identify innovative air quality monitoring techniques and assess their potential ability to meet Defra's medium to long-term (10-15 years) evidence requirements for national ambient air quality monitoring*

Not to pick specific "winners" or to endorse technologies, but to

- Examine the benefits and limitations of potential innovative technologies
- Map potential innovative technologies to Defra's current and developing needs

Background & policy context

Defra and the devolved administrations are required to demonstrate compliance with:

- Directives and air quality standards, at European and UK level
- International Protocols

This includes:

- Ambient Air Quality Directive and the 4th Daughter Directive
- UK's Air Quality Strategy (AQS)
- UNECE Gothenburg Protocol and its implementation in the EU as the National Emissions Ceilings Directive

Current approach

- The UK uses a hybrid approach that includes a mix of monitoring and modelling data to provide the evidence base to determine compliance with European air quality limits and national objectives

The over-arching aim is to deliver improvements in national air quality

What do innovative technologies need to measure?

- A broad range of air pollutants covered by existing legislation, including:
  - Oxides of nitrogen (NOx)
  - Ozone (O_3)
  - Particulate matter $PM_{2.5}$ & PM_{10}
  - Polycyclic aromatic hydrocarbons (PAHs)
  - Black carbon (BC)
  - Particle number
  - Nitrogen dioxide (NO_2)
  - Sulphur dioxide (SO_2)
  - Hydrocarbons
  - Metals – 4th Daughter Directive, e.g., arsenic, nickel, cadmium, lead
  - Ultrafine particles (UFP)
  - Particle speciation
- Potential to measure other parameters of interest, e.g.,
  - Meteorological parameters, e.g., wind speed and direction, temperature, relative humidity
  - Traffic density
  - Noise

Innovative technologies – key considerations (in no particular order)

- Use within the UK's national and local monitoring networks
- Maintenance of compliance monitoring to meet the DQOs defined in European air quality directives
- Provision of measurements to demonstrate fulfilment of both national and local air quality objectives
- Provision of improved data, e.g., improved spatial/temporal resolution
- Improved access to data, data analysis tools, additional observations, or the re-alignment of observations which could be of research value
- Reduced or limited costs over the lifespan of the monitoring technology

Contributors

- Study undertaken in collaboration with three nationally renowned project partners from the UK research community
- Instrument manufacturers and distributors provided insight into forthcoming innovative technologies
- Technology developers and end-users provided thoughts on potential future developments and evidence relating to the use of some of the techniques, in their current form

Study structure – two stage study

Stage 1 – to identify potential innovative air quality monitoring technologies

- Scoping study in the form of a questionnaire sent to stakeholders
- Responses were analysed and assessed to:
  - Identify potential innovative air quality monitoring technologies
  - Determine their benefits and limitations

Stage 2 – to identify *risks to innovation* and *market barriers* preventing adoption of these innovative technologies

- Technical limitations assessed in Stage 1, so not considered in Stage 2
- Risks to innovation and market barriers were collated from the responses
- Possible options were developed for each innovative technology that Defra (and other relevant stakeholders) could consider, including:
  - Ownership of the potential action
  - Priority rating
  - Ease of achieving the potential measure

Stage 1 – questionnaire

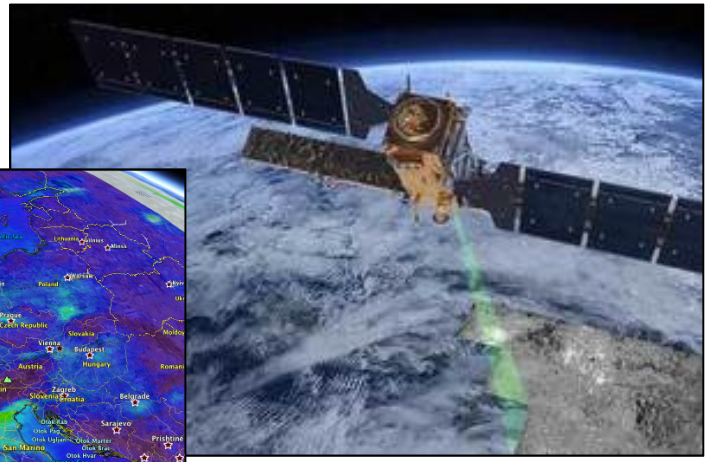
Purpose: To gather evidence from stakeholders and technology developers identifying…

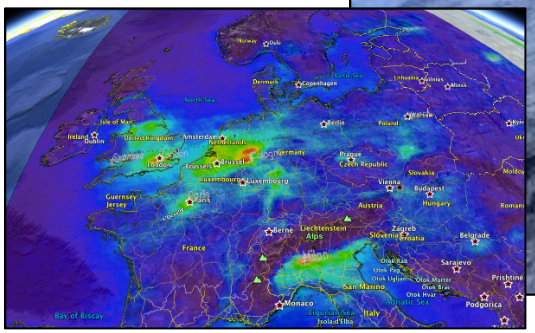
- Advantages and limitations of innovative technologies
- Factors driving the development of innovative technologies
- Perceived *risks to innovation* and *market barriers* to their development
- How the *risks to innovation* and *market barriers* might be overcome?

Examples of innovative technologies identified by the study

- Satellite-borne sensors

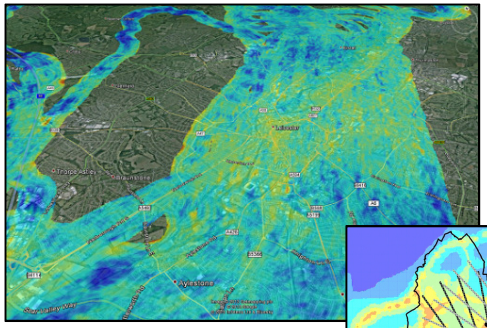
ESA Sentinel 1 satellite (right).

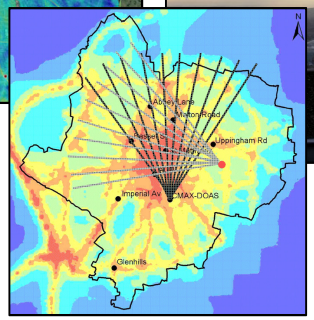




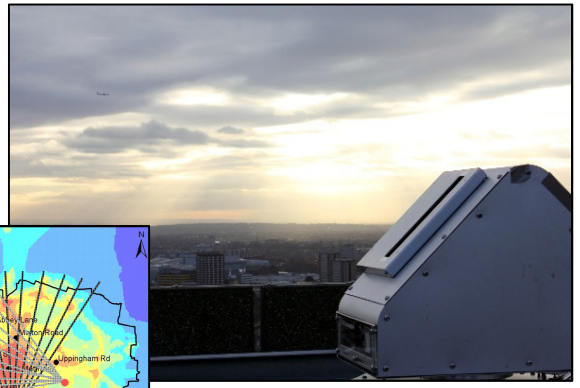
NO_2 concentrations over Europe (left) overlaid on Google Earth.

- Remote sensors (ground-based & airborne)





NO_2 slant columns measured over Leicester by the Airborne Air Quality Mapper.



CityScan (DOAS-based) instrument (top) and mapped NO_2 concentrations in Leicester.

- Pervasive sensors

Pervasive sensors (left) are active and automatic samplers. They employ electrochemical sensors (below) to measure gases and optical particle counters (light scattering cells) to measure PM.

- Fixed-point sensors

Differential UV Absorption Spectrometer (DUVAS): A multi-gas analyser (left). Micro-aethalometer (below).

Stage 1 – current limitations and benefits of satellite-borne and remote sensors

Limitations

- Satellite-borne sensors can't measure ground-level concentrations (~500 m limit)
- Satellite and airborne sensors can't measure through cloud!
- Spatial (and temporal) resolution cannot match current monitoring networks
- High measurement uncertainty for all species (except CO, CO_2), don't meet DQOs
- Provide column concentrations: Measurements incompatible with the Directive's requirements which state that measurements need to be in a *fixed volume of air*
- Expensive compared current technology & numerous technical hurdles to be overcome

Benefits *(the technology could…)*

- Provision of simultaneous and continuous measurement of multiple air pollutants
- Estimation of pollutant concentrations across large areas & between fixed point monitors
- Identification regional & local sources of air pollution affecting local air quality and city-scale mapping to identify hotspots or emission sources

Conclusions

- Unlikely to replace the UK's monitoring networks over the next 10-15 years; could provide supplementary evidence, e.g., fill-in-the gaps between fixed point measurements
- Could be used to validate and compile national emissions inventories

Stage 1 – current limitations and benefits of pervasive sensors

Limitations

- Currently unable to provide measurements equivalent with the requirements of the DQOs; measurement uncertainties are (*near*) acceptable for indicative measurements
- Limit of detection: Current ambient concentrations of air pollutants, e.g., NO_2, are typically low in the UK, unless at source. Can they be reliably measured?
- Replacement of sensors (whole device) required periodically – impact not well understood
- Cross-sensitivity of NO_2 sensors to ozone (O_3) and ambient oxidant loading

Benefits *(the technology could…)*

- Deployment in inaccessible locations; provision of high density, high spatial resolution networks capable of measuring air quality pollutants *plus* noise, position, meteorology
- Offer cost savings, especially if uptake is high (how true will this be in the long term?)
- Reduced reliance on dispersion modelling for in-street assessments. Modelling would still be required for remote areas and future scenarios.

Conclusions

- Pervasive sensors could supplement the UK's air quality monitoring in the medium term (5-10 years) and may have the potential to displace traditional, fixed point sensor

Stage 1 – fixed-point sensors

Four innovative active and automatic samplers were identified in this study that could potentially contribute to the UK air quality monitoring networks:

- Micro-aethalometers for measuring black carbon (BC)
- Optical particle counters (OPC) for measuring particulate matter, e.g., PM_{10} and $PM_{2.5}$
- Direct-measurement NO_2 analysers
- Differential UV Absorption Spectrometer (DUVAS) capable of measuring a range of gaseous pollutants.

Each of the technologies had different characteristics and potential for application in UK air quality monitoring networks.

All are available now and could, if required, be added to the UK's air quality monitoring network within the next 5-10 years

Stage 1 – current limitations and benefits of fixed-point sensors

Limitations

- Micro-aethalometer: No statutory requirement to measure BC, nice to have
- OPC: Current LAQM guidelines limit their use to screening and assessment studies; need to demonstrate equivalence with the DQOs before being used for compliance monitoring
- Direct-measurement NO_2 analysers: Cannot measure NOx, upon which the UK's national compliance modelling relies. Changing this approach would be difficult or impossible due to the complexity of atmospheric chemistry and the uncertainties in estimating primary NO_2 emissions
- DUVAS: Not demonstrated equivalence and capital cost of device may be equal to that of the gas sensors it displaces

Benefits *(the technology could…)*

- Micro-aethalometers: Portability could potentially offer greater spatial resolution and provide human exposure data
- OPC: Measure particle number and size, providing simultaneous estimates of $PM_{2.5}$ and PM_{10}. Portability offers higher spatial resolution measurements and range of applications
- Direct-measurement NO_2 analysers: Reduction in small over-estimations of NO_2 due to interferences from nitrogen compounds which affect chemiluminescent NOx analysers
- DUVAS: Measurement of a range of gaseous pollutants with one device could potentially displace several gas analysers. Mobile variant is available offering higher spatial resolution measurements for use in detailed assessments within the LAQM regime

Stage 1 – summary of key findings

- Stage 1 identified four technology groups that may supplement, or replace, some of the current monitoring instruments currently used in the UK's national air quality monitoring network in the next 10-15 years but *don't* currently fulfil the requirements of the air quality Directives

- Defra are continuing to monitor this situation

- Developers are responding to the on-going needs of the air quality monitoring market without intervention, including:
  - Development of satellite-borne and remote sensors to measure air quality pollutants
  - Development of electrochemical detectors and pervasive sensors for air quality monitoring, particularly in traditionally inaccessible locations
  - Development of miniaturised devices, e.g., the micro-aethalometer, for use in exposure studies
  - Development of devices, e.g., the DUVAS instrument, are capable of providing fixed-point measurements of multiple air quality pollutants

Study structure – two stage study

Stage 1 – to identify potential innovative air quality monitoring technologies

- Scoping study in the form of a questionnaire sent to stakeholders
- Responses were analysed and assessed to:
  - Identify potential innovative air quality monitoring technologies
  - Determine their benefits and limitations

Stage 2 – to identify *risks to innovation* and *market barriers* preventing adoption of these innovative technologies

- Technical limitations assessed in Stage 1, so not considered in Stage 2
- Risks to innovation and market barriers were collated from the responses
- Possible options were developed for each innovative technology that Defra (and other relevant stakeholders) could consider, including:
  - Ownership of the potential action
  - Priority rating
  - Ease of achieving the potential measure

Stage 2 – summary of key findings

- Initial results demonstrate that direct intervention by Defra is *not* currently required, but Defra are maintaining a watching brief

- Stage 2 of our study showed that there are four market barriers common to most or all of the technologies:
  - Standardised testing approaches
  - Equivalence testing: Demonstrating compliance/equivalence with reference methods
  - Development funding
  - Uptake amongst potential end users

  Other challenges may be identified as new technologies come to light

- Defra *could* consider potential supporting measures to engage and assist in developing innovative technologies, but these may need to be re-evaluated as new technologies emerge

Stage 2 – potential measures to reduce the risks to innovation and market barriers associated with satellite-borne sensors

Risk to innovation or market barrier and rationale	Satellite data cannot be used for compliance assessment & data reporting to the Commission – chiefly as a result uncertainty range of satellite data.	Lack of standardised approach for processing satellite data – may lead to confusion amongst potential end-users and limit uptake.	Accessing satellite data – difficult for non-specialist end-users to access satellite data.	End-user understanding – unfamiliar with satellite data products and unaware of what the "best" datasets are for AQ applications.	Understanding of data storage needs – requires significant dedicated resources, e.g., staff, computers and data storage.
Source of potential measure	Project Team	Project Team	Project Team	Project Team	Project Team
Potential measures and steps to achieving potential measure. ***Defra could….***	• Liaise with EC (DG ENV and JRC) to identify possible adjustments to the AQ Directives. • Engage with European Environment Information and Observation Network (EIONET) on suitable standards for satellite-borne sensor measurements. • Establish UK working group to develop proposals for DQO for satellite data. • Establish a working group to develop proposals for DQO for remote sensor data.	• Engage with UK and European partners to standardise data processing and products to convert raw data into ready-to-use data products for use in air quality applications. • Form a working group to develop standard data processing approach.	• Engage with UK and European partners (e.g., UK Space Agency, UK Catapult Satellite Applications, ESA, and the Copernicus programme) to develop a European-wide platform to provide satellite data products to act as potential "one-stop shop" for satellite data. • Engage with UK experts to identify satellite data products of use to potential end-users. • Encourage engagement between data-providers and end-users to understanding of data requirements.	• Consult with UK experts to identify suitable satellite products of use to air quality end-users, with the lowest uncertainty and highest spatial and temporal resolution.	• Develop guidance for potential end-users on satellite data management and storage.
Action owner	• UK and European commercial and research community. • Defra to lead engagement.	• UK and European commercial and research community • Defra to facilitate engagement	• UK and European commercial and research community • Defra to facilitate engagement	• UK Catapult Satellite Applications • UK commercial and research community • Defra to facilitate engagement	• UK Catapult Satellite Applications • UK commercial and research community • Defra to facilitate engagement
Priority rating	High	High	Medium	Medium	Low
Ease of achieving potential measure	Difficult	Moderate	Moderate	Easy	Moderate

Stage 2 – options Defra *could* consider to overcome the "*risks to innovation*" and "*market barriers*" facing innovative technologies

	Risk or barrier	Options Defra *could* consider…
1	Standardised testing approaches – Processing raw satellite data into final data products – Validating the performance of satellite-borne sensors – Validating the performance of remote sensors – Validating the performance of pervasive sensors – Inferring particulate loadings from particle number counts	Defra to facilitate dialogue with stakeholders and partners, including: • European Environment Information and Observation Network (EIONET) • UK and European partners (e.g., UK Space Agency, UK Catapult Satellite Applications, ESA, and the Copernicus programme) • EC (DG ENV and JRC) • UK and European commercial and research community • Environment Agency (MCERTS scheme)
2	Equivalence testing	
3	Development funding	Technology developers to lead
4	Uptake amongst potential end users	

Conclusions – Stage 1

- Stage 1 identified four technology groups that may supplement, or replace, some of the current monitoring instruments currently used in the UK's national air quality monitoring network in the next 10-15 years but *don't* currently fulfil the requirements of the air quality Directives

- Defra are continuing to monitor this situation

- Developers are responding to the on-going needs of the air quality monitoring market without intervention, including:
  - Development of satellite-borne and remote sensors to measure air quality pollutants
  - Development of electrochemical detectors and pervasive sensors for air quality monitoring, particularly in traditionally inaccessible locations
  - Development of miniaturised devices, e.g., the micro-aethalometer, for use in exposure studies
  - Development of devices, e.g., the DUVAS instrument, are capable of providing fixed-point measurements of multiple air quality pollutants

Conclusions – Stage 1

- Initial reviews demonstrate that these novel applications could offer:
  - Higher spatial resolution data
  - Personal monitoring and access to traditionally inaccessible locations
  - Possibility for reduced costs due to smaller sized devices and lower operating costs
  - Co-benefits – data for verifying emissions inventories
  - Improved access to data and new approaches to using air quality data
- Most technologies have technical issues – such as a need for improving uncertainty levels or defining common calibration methods
- Other technical limitations may be identified as this review process continues or technologies emerge

Conclusions – Stage 2

- Stage 2 showed that there are four market barriers common to the technologies identified in our recent study:
  - Standardised testing approaches
  - Equivalence testing
  - Development funding
  - Uptake amongst potential end users

LJ12

- The evidence gathered from our study suggested that developers are responding to the on-going needs of the air quality monitoring market without direct intervention from Defra, but Defra are continuing to monitor this situation

Slide 22

LJ12 It might be helpful to give some indication as to the length of time Defra will be maintaining a watching brief

Lingard, Justin, 15/03/2016

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Air Quality in Scotland Seminar

22nd March, 2016

Optional slides to be added as required but these may require tailoring further

Standardisation of measurement methods and demonstration of equivalence

- Standards issued by the European Committee for Standardisation (CEN) ensure comparable measurements throughout Europe
- Methods must undergo equivalence testing against a "*reference method*"
- "*Equivalent methods*" and "*indicative measurements*" conform to the data quality objectives (DQOs) for data capture and measurement uncertainty
- Air quality Directives require measurements to be taken at *fixed points* and *within a fixed volume of air*

Pollutant	CEN Standard	Reference measurement method	Minimum data capture (%)	Equivalent method: Uncertainty (%)	Indicative measurement: Uncertainty (%)
Carbon monoxide	EN14626	IR spectroscopy	90	±15	±25
Nitrogen dioxide	EN14211	Chemiluminescence	90	±15	±30
Ozone	EN14625	UV photometry	90	±15	±30
$PM_{10}/PM_{2.5}$	EN12341	Klein Filtergerät	90	±15* *(*UK uses TEOM-FDMS)*	±50
Sulphur dioxide	EN14212	UV fluorescence	90	±15	±25

Stage 1 – study limitations

- Short timescale limited the window of opportunity to consult with stakeholders and gather evidence on innovative technologies
- Limited evidence, responses or assessment of technologies, could have lead to a low risk assessment score
  - Mitigated by the project team and academic partners using professional judgement and technical knowledge to assess the risks
- Commercial confidentiality may have prevented some manufacturers revealing sensitive information about technologies & responding to the questionnaire
- The study did not include time to return to stakeholders to follow-up and discuss their responses
  - This may have generated more insight and depth into the stakeholders' assertions and provided supporting evidence

Stage 1 – definitions and stakeholder consultation

Definition of an “innovative technology” was unbounded but could be…

An instrument, sampler, sensor (active or passive), method, or system (partially or fully integrated)…

– or –

A satellite-borne sensor or measurement device…

– or –

A remote sensing technique…

…that would provide air pollutant (gaseous and/or particulate-phase) measurements.

Stakeholders consulted, in the UK and overseas:

- Air quality instrument manufacturers and suppliers
- Organisations involved in the development of innovative technologies, e.g., universities and research organisations
- Other stakeholders, e.g., users with experience of using some of the innovative technologies, e.g., as part of UTMC systems

Stage 1 – summary of findings

The questionnaire responses identified four broad technology groups:

- Satellite-borne sensors: Typically DOAS-based devices
- Remote sensors: Airborne (aircraft, UAV) or ground-based air quality monitoring sensors, typically DOAS-based devices, which could offer higher spatial resolution
- Pervasive sensors: Small-form devices utilising electro-chemical sensors providing air quality (and other parameters of interest) measurements in traditionally inaccessible locations, e.g., at height, in remote locations, or configured to provide high-density multi-sensor networks
- Fixed-point sensors: Active and automatic analysers similar to those currently used within the UK's national air quality monitoring networks

No innovative *passive sampling techniques* were identified by this study

Work focused on identifying innovative technologies capable of providing air quality measurements not emissions measurements

- Some innovative technologies, however, could serve a dual purpose, supporting the compilation & validation of emissions inventories, e.g. remote & satellite-borne sensors

Stage 2 – definitions of "risks to innovation" and "market barriers"

Examples of "*risks to innovation*" include:

- Limited supply access to a technology of knowledge
- Restricted knowledge transfer, small knowledge base
- Underfunding
- Lack of market acceptance or difficulties accessing the market – if resulting from an information or awareness issue, a regulation issue or a development issue, e.g.,:
  - Lack of awareness that a technique is available or suitable
  - Insufficient information about a technique's performance
  - Regulation or guidance that does not mention or cover the new technique.
    - Potential users therefore do not know if they are allowed to use the technique, or how they should do so. (Lack of market demand alone is not a barrier in this context.)

Examples of "*market barriers*" include:

- Physical constraints such as limitations in technological ability.
- Legislation – is legislation, in UK or European, designed to encourage development?
- Requirements for the use of reference methods, the Monitoring CERTification Scheme (MCERTS) for type approval and the ongoing demonstration of equivalence.

Stage 2 – priority ratings and definitions

Priority ratings and definitions used to categorise the risks to innovation and the market barriers

Priority rating	Description
High	Major risks to innovation and market barriers need to be resolved immediately (within 1-5 years) as they could severely impede innovative technologies coming to market within the next 10-15 years.
Medium	Moderate risks to innovation and market barriers need to be resolved in the medium term (within 5-10 years) and are less urgent than major risks, e.g., an adequate workaround may exist. They could impede innovative technologies coming to market within the next 10-15 years. Once major risks to innovation and market barriers are resolved these may become a higher priority but this would need to be re-assessed in time.
Low	Minor risks to innovation and market barriers, which are unlikely to the innovative technologies coming to market within the next 10-15 years and have negligible effect.

Lack of standardised approaches

- Lack of standardised approaches to:
  - Processing raw satellite data into final data products
  - Validating the performance of satellite-borne sensors, remote sensors or pervasive sensors
  - Inferring particulate loadings from particle number counts (derived from OPC)
  - No suitable CEN standard methods for the innovative technologies identified here
- This makes it difficult for them to demonstrate equivalence with the DQOs
- Since May 2015 a new CEN Working Group, WG42, is working towards standard methods for assessing the performance of pervasive (gas) sensors
- Defra have started to engage with EIONET on suitable standards for satellite-borne sensor measurements, but this process is in its infancy
- Defra and the Commission may wish to consider whether similar Working Groups would benefit other innovative technologies – none exist for satellite-borne sensors, remote sensors, or particulate matter pervasive sensors

Equivalence testing

- Equivalence testing is necessary for non-reference techniques
  - Technologies must demonstrate measurement robustness and ability to comply with UK and EU measurement standards such as DQOs stated in the air quality Directives.
  - It can take 1-2 years for gas analysers, and up to 5 years for particulate matter instruments, to demonstrate equivalence
  - The perceived inflexibility in accepting new technologies is believed to increase development costs
- Defra could consider how to introduce flexibility into the regime ***without*** "watering down" standards and ensuring compliance with the European air quality Directives
  - Consult with stakeholders to identify where improvements could be made
  - Determine the potential to streamline and/or tier the equivalence testing process
  - Make the equivalence testing more responsive and adaptable to the assessment of innovative technologies as they come to market
  - Recognise that there are different potential markets for different sensors

Development funding

- Lack of access to development funding, developers' awareness of access to funding streams, or the extent to which it is posing a risk to innovation or a market barrier weren't understood fully
- Possible funding streams:
  - Space Applications Catapult for Satellite-borne sensors and satellite data products
  - Electronics, sensors and photonics theme area of Innovate UK for pervasive sensors
- Defra runs research competitions and LAs provide small grants through the LAQM regime, but does not provide funding *per se*
- Defra could identify links between innovative technologies and priority areas, such as those within its "One Monitoring Strategy"
  - Consider the direct and co-benefits offered, e.g., the use of remote sensing techniques (satellites and aircraft-borne sensors) to provide air quality monitoring data and precision farming data, both of which could be of value to Defra, and other end-users
- Developers may wish to consider the development of end-user applications that could deliver income, in addition to sensor sales, once they come to market

Uptake amongst potential end users

- The potential for limited uptake amongst potential end users – not just those in the AQ community – was inferred by the project team from the stakeholder responses
- Need to raise awareness and to publicise the benefits of innovative technologies
  - Not necessarily the role of Defra or other regulators
  - Costs should probably be met by developers, e.g., through marketing days
  - Innovative technologies need to demonstrate they are fit for purpose, i.e., capable of demonstrating equivalence
  - Developers need to ensure that innovative technologies overcome their short-comings
  - Encourage linkages and KT, e.g., amongst the UK's space user community
- Current regulations and practices may be inadvertently creating resistance to change
  - Updating LAQM TG.09 (published in 2009)
  - Linkages with other strategic documents – planning, transport, public health
- Creation of an internet portal to provide linkages with public and citizen science projects
- Further assessment would be required to understand whether this is a valid concern

Stage 2 – potential measures to reduce the risks to innovation and market barriers associated with remote sensors

Risk to innovation or market barrier and rationale	DOAS data cannot be used for compliance assessment purposes and data reporting to the Commission – current AQ Directives do not permit the use of remote sensors.	Lack of standardised approach for processing remote sensor data – may lead to confusion amongst potential end-users and limit uptake.	Limited availability of data and software tools for data handling, analysis and display – data processing requires specialist software and specialist knowledge to use.
Source of potential measure	Project Team	Project Team	Questionnaire
Potential measures and steps to achieving potential measure. ***Defra could….***	• Liaise with EC (DG ENV and JRC) to identify possible adjustments to the air quality Directives to allow use of remote sensor data. • Engage with EIONET on suitable standards for remote sensor measurements. • Establish a working group to develop proposals for DQO for remote sensor data.	• Engage with UK and European partners to form working group to develop standardised method to convert raw data into ready-to-use data products for use in air quality applications.	• Develop guidance for potential end-users on the use and processing of remote sensor measurements. • Encourage stakeholders to make remote sensing data more widely available. • Promote knowledge sharing between UK experts and end-users. • Identify UK software developers with the capability to develop tools that would handle, analyse and display data.
Action owner	• UK and European commercial and research community. • Defra to lead engagement	• UK and European commercial and research community • Defra to facilitate engagement	• UK commercial and research community • Defra to facilitate engagement
Priority rating	High	High	Low
Ease of achieving potential measure	Difficult	Moderate	Moderate

Stage 2 – potential measures to reduce the risks to innovation and market barriers associated with pervasive sensors

Risk to innovation or market barrier and rationale	Pervasive sensors data cannot be used for compliance assessment purposes and data reporting to the Commission	Lack of standardised approach for calibrating and testing pervasive sensors or demonstrating equivalence – may lead to confusion amongst potential end-users and limit uptake.		Lack of a peer reviewed performance assessment of pervasive sensors – a robust assessment may provide credibility promoting greater uptake.
Source of potential measure	Project Team	Questionnaire		Project Team
Potential measures and steps to achieving potential measure. ***Defra could….***	• Establish UK working group to develop proposals for compliance assessment & data reporting DQO for pervasive sensors	• Engage with the recently established WG42 on *gas sensors*. • Develop standard testing and evaluation protocols for gas sensors focusing on assessing the performance of (1) sensors within a batch, and (2) sensors in different devices.	• Expand remit of WG42 to cover particle sensors, or encourage formation of new WG to look into this issue. • Develop a standardised approach for inferring particulate loadings from particle number counts.	• Undertake a peer-reviewed evaluation of the technology, and data collected to date, e.g., from field measurements and manufacturer testing, or a combination of the two. • Report on findings.
Action owner	• UK commercial and research community commercial and research community Defra to lead engagement	• UK commercial and research community • Defra to facilitate		• UK commercial and research community • Defra to facilitate
Priority rating	High	High		High
Ease of achieving potential measure	Difficult	Moderate	High	Moderate

Stage 2 – potential measures to reduce the risks to innovation and market barriers associated with fixed-point sensors

Risk to innovation or market barrier and rationale	Lack of standardised approach for converting particle number counts into particulate mass loadings – may limit uptake of OPC amongst end-users.
Source of potential measure	Project Team
Potential measures and steps to achieving potential measure. ***Defra could….***	• Develop a standardised approach for inferring particulate loadings from particle number counts.
Action owner	• UK and European commercial and research community • Defra to lead engagement
Priority rating	High
Ease of achieving potential measure	Difficult