Policy Report Assignment

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RE: Environment Act 2021 - Innovating Air Pollution Monitoring for More Targeted Policy Outcomes.

Executive summary

This policy brief suggests avenues of improvement for the UK's air quality policy, whose most recent development consists of the 2021 Environment Act. The field of air quality control has been characterized by difficulties in meeting internationally agreed-upon standards and assessing the effectiveness of interventions, partially as a result of a disintegrated approach to policy implementation. Given the urgency of the climate crisis, the abundant availability of air quality and IoT data, and the propensity for increased reliance on data-driven solutions, the UK government should consider developing an air quality Digital Twin. Making use of real-time data in combination with visualization tools will provide policymakers with a more complete understanding of the effects of air quality interventions and long-term air quality policy outcomes. In turn, this will lead to more targeted policies to the benefit of citizens and the international community. The brief also suggests closer collaboration between public agencies, and in particular between the Department for Environment Food and Rural Affairs (Defra) and the Department for Business, Energy and Industrial Strategy (BEIS), whose Ministers are being here addressed.

Air quality policy context in the UK

The UK government regards air pollution as one of the greatest risks for the health of its citizens (Public Health England, 2018). Air quality standards are important not only on a national level, but also on an international level, as many international agreements attempt to mitigate the effects of climate change. In particular, the WHO highlights the health risks derived from exposure to particulate matter ($PM_{2.5}$ and PM_{10}), ozone, nitrogen dioxide, sulfur dioxide and carbon monoxide, and establishes acceptable thresholds of exposure (World Health Organization, 2021). Such thresholds have been employed by the EU to regulate air quality standards for its Member States.

Even though, the UK is no longer a Member State, supranational regulation has been implemented into national law.

Especially in cities, levels of NO_2 and $PM_{2.5}$ often exceed the limits established by the WHO. In 2014, the European Commission initiated infringement proceedings against the UK for failing to comply with regulation (European Commission, 2014). Private proceedings were also brought forth, which eventually required the UK to draft new plans for meeting air quality standards. Following Brexit, European institutions have lost their enforcement powers, however, newly created bodies have come to replace them.

On a national level, the 1995 Environment Act sets out national air quality standards which should be met by aid of delegation to local authorities (Environment Act, 1995). Defra is then responsible for coordinating Action Plans for the country as a whole. Even though, the involvement of local authorities for the planning and measurement of air quality objectives might seem beneficial, critics argue that the divergence in national and EU policies for what regards responsibility attribution and reporting resulted in the poor implementation of both (J.H. Barnes et al., 2018).

The most recent development is the 2021 Environment Act, which is a legally binding document establishing concrete environmental objectives in four key areas - air quality, water, biodiversity, and waste reduction (Environment Act, 2021). Updated air quality goals include an "Annual Mean Concentration Target" and a "Population Exposure Reduction Target", which aims for a 35% reduction in exposure for the population (UK AIR, n.d., a). The document imposes new measures aimed at tackling smoking and domestic burning, but most importantly, it highlights a commitment to finding new ways to tackle air pollution, with an eye to responsible behavior of both citizens and the government.

Meeting targets - on paper or in practice?

Even though a few improvements are being made on paper, it is difficult to identify palpable improvements. In general, air pollution measurements are prone to errors, given that they rely on sensors, thus further complicating the nature of impact assessments. For example, the Air Quality Expert Group (AQEG) reports on the uncertainty of $PM_{2.5}$ measures, given the existence of various measurement methods (AQEG, 2022).

Another concern raised by the Act relates to the required timeframe for reporting. Coupling annual reports with population exposure seems counterintuitive given that the spread of air pollution cannot be averaged evenly across time and space. Air quality differs across locations, depending on various factors such as weather conditions or the presence of particular sources of pollutants. Existing initiates demonstrate that pollutant levels might even differ within a single city block, and that concentrations differ across times of the year, days of the month, or even hours of the day (Kallay, 2023). Therefore, the population's exposure cannot be regarded as an average, especially when factors such as the socioeconomic status of a citizen might determine individual exposure levels.

Finally, the Act is attempting to stimulate innovative ways of tackling air pollution, however, in practice it is unclear which improvements are being sought. This paper proposes a data-driven approach to air quality policy, which will enable clearer measurements, more comprehensive impact assessments related to time and space, and an innovative outlook to air quality measurements with a focus on citizens' needs. Furthermore, data-driven solutions will address critiques that point to the ineffectiveness and disintegrated nature of the air quality policy institutional setup. In fact, standardization within a digital environment will enable the integration of local and national components.

Air quality policy, particularly as it relates to citizen's health and quality of life, falls within the remits of Defra, however, BEIS should also be addressed, as it is responsible for greenhouse gas emissions policy, whose outcomes aim to improve air quality. The two departments would benefit from closer collaboration, and from the joint adoption of innovative data-driven techniques for air quality monitoring. BEIS has already initiated projects aimed at exploiting data-driven solutions for, among other aims, a "reduced impact on the environment" (National Infrastructure Commission [NIC], 2017). Closer collaboration for air quality is desirable, as it is of paramount importance for other nation-wide objectives which include the advancement of the Sustainable Development Goals, and the ambitious goal of reaching Net Zero by 2050 (HM Government, 2021). An innovative approach to environmental policy is thus important if the UK wants to meet internationally agreed-upon standards, not only on paper, but also in practice.

Suitability of a data-driven approach

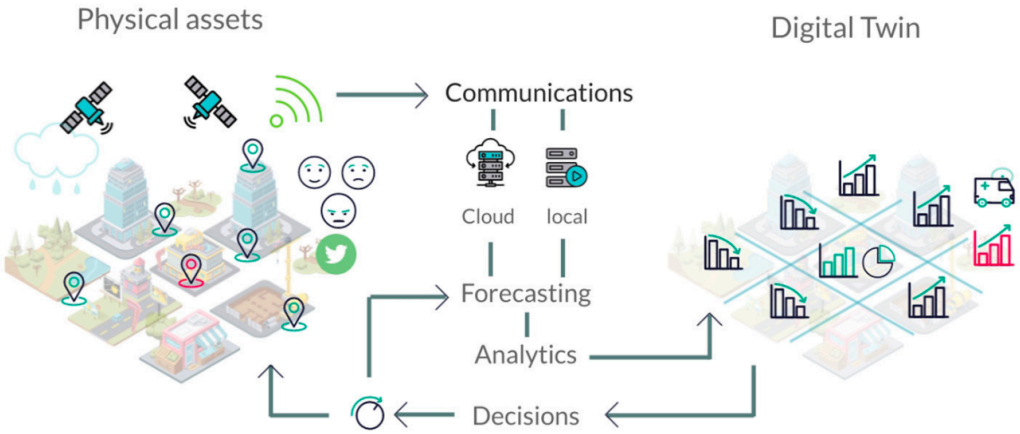
Today's atmosphere is increasingly shaped by new factors such as the smartification of cities, the decarbonization of businesses and transport, and changing human patterns. The introduction of these factors requires a reevaluation of how air quality modeling is conducted (Topping et al., 2021). A new approach could leverage the potential of data analytics to yield actionable results. This is especially the case when considering the amount of air quality data already being collected in the UK. The Air Information Resource provides three types of data which include monitoring, descriptive statistics and exceedance statistics data. Over 1500 sensors are placed across the country, many of which are automatic and thus able to autonomously collect hourly pollutant levels. These information are publicly available and include visualization options through graphs (UK AIR, n.d., b). Such data availability could be leveraged to extract more insights when combined with data produced by IoT devices across smart cities. Policymakers and urban planners would then be presented with the opportunity of addressing air quality objectives in a more targeted way, by observing real-time changes in pollutants levels following interventions.

As remarked by Kettl (2017), data has the potential to tell compelling stories, thus helping policymakers to understand the world better and to make more informed policy decisions. However, this potential does not exist on its own. It requires skilled experts and data analysts who can ask the right questions, identify the correct patterns and present new knowledge in an understandable but complete way. The ability to "tell the story" is important because the phases of the policymaking cycle might at times be disconnected from each other, and they might involve various sets of actors with different expertise, whose priorities might clash. Therefore, the author highlights the usefulness of relying on good data visualization methods which can present statistical facts through charts and maps. Kettl's remarks hold true for what regards air quality policy, as tying established targets with interventions and their derived outcomes has proven to be a difficult task. In addition, the UK holds a poor record when it comes to meeting standards, and commentators note that a disintegrated institutional setup worsened the disconnect between policies and their desired effect (Barnes et al., 2018). This is why, existing sensor data should be better employed, not only to create more insights, but also to better visualize existing problems, and provide a compelling story across all phases of the policy cycle.

Digital Twins and virtual monitoring

The potential of data visualization is fully unlocked by Digital Twins, an emerging technology consisting of a virtual representation of an existing system, which is able to automatically update as real-world conditions change (Fuller et al., 2020). Virtual twins of UK cities would enable the integration of IoT components and data analytics, so as to create a virtual representation of physical elements. Importantly, Digital Twins rely on statistical modeling and AI to create a counterpart of the real world alongside its interpretation, so they would not only serve as tools for assessing the impact of interventions, but also to model envisioned strategies and predict their effectiveness before they are implemented. Research suggests that modeling platforms that provide simulations of pollutants levels are crucial for improving the quantification of policy outcomes (Viaene et al., 2016). The AQEG notes that modeling is useful both before and after interventions are carried forth, however, modeling techniques have not been employed (AQEG, 2020).

Figure 1



Note: A schematic showing how data generated from physical assets that are used to monitor an urban environment are used to build a virtual counterpart; the Digital Twin. Using a range of forecasting and analytics allows scenario playback and the potential impacts of interventions to be assessed. Adapted from "Digital Twins of Urban Air Quality: Opportunities and Challenges", by D. Topping et al., 2021, Frontiers in Sustainable Cities, *3*, p. 2. Copyright 2021 Topping, Bannan, Coe, Evans, Jay, Murabito and Robinson.

The Healthy Outdoor Premises for Everyone (HOPE) project provides an example of the development of a Digital Twin for air quality modeling. It was conducted in the city of Helsinki and demonstrates how the integration of sensor data within a virtual twin environment improves urban planning, pollutant migration, and individual exposure (Kallay, 2023).

Several lessons learned from HOPE can inform the UK's future air quality initiatives:

- ***Visualization*** tools can support city planning projects.
- Mid- and low-cost ***sensors*** can be effective when deployed in a network.
- ***Ultrafine particles (UFPs)***, which are normally difficult to detect, can be measured by using lung deposited surface area and black carbon concentration as statistical proxies. This is a valuable conclusion given that UFPs can penetrate the lungs more deeply and create greater health risks. Further research into air quality measurements could identify other cases where statistical tools enable improved detection of harmful substances.
- ***Innovation competitions*** were promoted through the project, whose winners had the opportunity of implementing their digital solution to air quality visualization. This led to ten solutions being implemented, many of which relied on ***open source data***.
- ***Citizen involvement*** was a key component of the project, which partially relied on crowdsourcing, as volunteers carried portable sensors and shared their individual exposure levels. A broader campaign served to create ***awareness***, which could stimulate citizens to become more conscious of air quality and modify related behaviors.

Adopting a data-driven approach could thus solve some of the problems previously identified. Firstly, statistical techniques could be further developed to improve pollutants measurements, including by means of proxies, and to develop modeling techniques able to predict policy outcomes. Secondly, data visualization tools would make it possible to communicate technical and scientific knowledge to policymakers and to the wider public more effectively and transparently. Thirdly, a Digital Twin of air quality integrated within the smart city landscape would address the temporal and spatial limitations of annual average measurements which are hardly representative of citizen's individual exposure levels. Lastly, the presented approach is centered around citizens, and aims for increased awareness and participation, including from universities and companies willing to collaborate on innovation.

Existing digital framework - Data for the Public Good

The UK holds the advantage of having already launched initiatives aimed at stimulating the use of data for the public benefit. The Data for the Public Good report mentions that one of the impacts of improved data use is a reduced impact on the environment. It also highlights safety and security requirements of data sharing, whose further development is entrusted to the Center for Digital Built

Britain (CDBB). The role of Digital Twins is mentioned in relation to data management, and is presented as a tool for the UK to acquire a leading position given the country's research capabilities (NIC, 2017). Following the report's recommendations, the CDBB produced the Gemini Principles establishing the core values which should guide the development of a national Digital Twin (see figure 2, Bolton et al., 2018). CDBB, in collaboration with the University of Cambridge also created the Digital Twin Hub, whose purpose is that of supporting the development of Digital Twins by creating a network of partners and engaging with various sectors (Digital Twin Hub, n.d.).

Figure 2

Note: The Gemini Principles. Adapted from "The Gemini Principles: Guiding values for the national digital twin and information management framework" by A. Bolton et al., 2018, p. 6. Copyright 2018 Centre for Digital Built Britain and Digital Framework Task Group.

To conclude, the explicitly voiced missions of the UK in relation to climate action and data-driven growth would seem to support this paper's proposal. Since several initiatives have already been brought forth, it would be beneficial to further develop them to advance the country's stated missions.

Limitations

The central component of the proposed policy initiative is the application of statistical tools, machine learning, and data visualization, which requires sufficiently apt IT infrastructure. Relying on good infrastructure ensures that data can be correctly collected, calibrated, standardized, visualized, and that standards of trust, privacy and sustainability can be upheld (Topping et al., 2021). Particularly, meta-data stemming from various sources should be stored in unified formats,

and communication between systems should be reliable and fast, perhaps making use of 5G networks (Topping et al., 2021). The provision of such infrastructure can represent an initial hurdle, also considering budgetary resources. For example, graphics processing units (GPUs), which are able to execute algorithms can range from $1,000 to $10,000 (Fuller et al., 2020). Other technological limitation in relation to Digital Twins are categorized by Fuller et al. (2020), who identify common grounds between data analytics and IoT limitations (see figure 3). Trust and expectations represent diverging attitudes to data analytics and AI. On the one hand, it is important to recognize the potential of ethical and human-centered uses, on the other hand, expectations should be shaped by a cautious and eager-to-learn approach (Fuller et al., 2020). Some of these technological limitations could be overcome by adhering to the Gemini Principles, by making use of cloud computing systems for data handling and visualization, and by investing in connectivity infrastructure.

Figure 3

Digital Twin	
Data Analytics	***Industrial IoT/IoT***
IT Infrastructure	IT Infrastructure
Data	Data
Privacy	Privacy
Security	Security
Trust	Trust
Expectations	Expectations
	Connectivity

Note: Shared challenges. Adapted from "Digital Twin: Enabling Technologies, Challenges and Open Research", by A. Fuller et al., 2020, *IEEE Access*, *8*, p. 108958.

Another hurdle relates to the technical skills required to both develop and successfully make use of Digital Twin environments. Given that digital literacy in the public sector is often low, programs aimed at improving digital skills should be advanced. Several initiatives already exist, such as the National Data Strategy (Gov.UK, 2020). Alongside training public staff, it is important to consider hiring data experts. They would be entrusted the responsibility of steering Digital Twins developments and collaborating with policymakers for the purpose of "telling the story". Thus, budgetary allocations should be reserved not only for physical and data infrastructure, but also for the training and hiring of new staff. These economic limitations could be partially overcome by employing an open government approach to innovation and fostering further collaboration with universities.

Finally, social and political limitations of the proposal should be considered. Government agencies will have to undergo important changes. This might cause momentary instabilities, which could shape attitudes towards the project. The element of trust needs to be present both within and outside of government. The open nature of the project makes citizen's input particularly important, thus also exposing it to backlash by those who do not have trust in AI or do not regard the project's objectives highly. These limitations could be overcome by conducting awareness campaigns, including through social media, and continuously emphasizing adherence to the Gemini Principles.

Recommendations

1. Invest in ***IT infrastructure*** and ***data expertise***.
2. Develop a ***Digital Twin for air quality monitoring***. This will lead to improved use of statistics for air quality measurement, clearer policy outcomes, and improved policies based on prediction.
3. Emphasize the ***Gemini Principles*** at each stage of the policy cycle.
4. Make use of data visualization to ***tell a story***. This will ensure the cohesiveness of the project across policy stages and across departments.
5. Improve ***digital literacy*** among government employees, including by expanding existing initiatives.
6. Avoid duplication of efforts by ensuring that the ***CDBB*** and the ***Digital Twin Hub*** are involved.
7. Foster citizen engagement and collaboration with other entities by employing a receptive ***open government approach***.
8. Open avenues of ***collaboration between government departments***. Particularly, Defra and BEIS share common objectives and would both benefit from the project. Furthermore, input from other government departments should be encouraged, since air quality control might affect or be affected by other policy areas related to, inter alia, traffic control, public transport, urban planning, health, and social justice.

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