End-users and new air-quality monitoring technologies

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Abstract

This thesis analyses the application of emerging air-quality monitoring practices in three cities: York (UK), Berlin (Germany) and Seoul (South Korea). Drawing upon primary interview data and extensive primary and secondary literature the research reviews air-quality monitoring in the three cities and identifies factors that shape the adoption of new air-quality monitoring practices. The analysis focuses upon the perceptions and roles of end-users of air quality data. The project develops an end-user stakeholder framework, which is used to classify and interpret the rationale behind end-users' interpretations of emerging air-quality monitoring technologies. The findings show that new technologies diversify end-users' involvement in air-quality monitoring, diverting from legislative compliance-monitoring to multi-functional societal practices.

The analysis reveals different interpretations of emerging monitoring technologies, that are shaped by the social-political contexts in which they are deployed and the complexity of air pollution management in cities. The research makes original contributions to interdisciplinary work analysing emerging low-cost air-quality sensors by developing a new analytical category, the end-user stakeholder, and establishing the needs of these end-users in relation to urban air-quality monitoring.

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Declaration

I declare that this thesis is a presentation of original work and I am the sole author. This work has not previously been presented for an award at this, or any other, University. All sources are acknowledged as References.

Chapter One Introduction to the study

1.0 Introduction

Ambient air pollution caused more than three million premature deaths globally in 2012 (WHO, 2014). A recent report revealed that 92% of the world's population is exposed to air pollution levels that exceed the World Health Organisation (WHO) limits, putting citizens at additional risks of respiratory diseases and other health problems (WHO 2016). At the same time, the world continues to be urbanised. Currently more than half of the world's population lives in cities, which continues to grow - 66% of the world's population will be urban by 2050 (UN 2014). Fast urbanisation creates jobs, wealth, better living conditions and health care. Yet despite these advantages, many cities face pollution problems due to transportation, increasing energy consumption and industrial production in or for cities (Brancheau and Wetherbe, 1990; Mage et al., 1996; Gurjar et al., 2008). Therefore, it is clear that cities must be part of the solution if an urbanising world is to grapple successfully with environmental challenges, and ambient air quality represents one of the most pressing challenges.

This thesis addresses this challenge by analysing the scope for new monitoring technologies to help address air pollution in three urban setting (York, Berlin and Seoul). In a departure from existing studies and as part of a burgeoning literature responding to the emergence of new technologies on the ground (for instance, Bales et al., 2014; Kumar et al., 2015; Lewis et al., 2016; Castell et al., 2017), the thesis engages critically with the questions of whether the data generated by new handheld devices (such as phones) can be useful to stakeholders in helping to develop effective air pollution abatement regimes in cities. The thesis develops a novel concept – the end-user stakeholder – to better capture the role played by certain key actors in using data provided by air quality monitoring. Interestingly, while the original aim of the thesis was to engage with a relatively narrow technical question about whether new data are useful to particular users, the findings highlight the importance of politics in mediating and shaping who might find data from new devices useful. The thesis finds that air-quality monitoring is a multi-purpose societal activity, which could fit both regulatory and non-regulatory purposes depending on the social and political positions of end users. The results show that due to the technical performance of current sensors, emerging low-cost monitoring practices primarily fit non-compliance purposes.

In the following sections of this chapter background information on the evolution of urban air quality regimes is provided (Section 1.1 and 1.2). Section 1.3 provides the aims and main research questions of the study. The final section of the chapter provides an overview of the thesis.

1.1 General Context

Addressing air pollution involves a range of complex issues. Air quality problems are related to atmospheric chemistry, meteorological conditions and the wide range of emission sources. Key pollutants of concern identified by the WHO include carbon monoxide (CO), nitrogen oxides (NOx), sulphur dioxide (SO_2), particulate matter (PM), and ground level ozone (O_3) (WHO, 2016). These pollutants can be emitted directly from primary sources or produced through secondary formation via chemical reactions in the air. Some pollutants can travel and be deposited far away from the original source. For example, particulate matter, a mixture of solid particles and liquid droplets of various sizes, can be emitted from domestic and hundreds or even thousands of kilometres away from the sources (WHO, 2006; European Parliament, 2014; Harrison et al., 2014; Royal College of Physicians, 2016). Meteorological conditions also affect the behaviour of pollutants leading to variability in their manifestation. Therefore, from the national to the local level, there are trans-boundary issues associated with urban air pollution. External contaminants enter urban areas carried by prevailing winds in addition to those endogenously generated. As such, air pollution abatement requires effective control of a broad spectrum of both primary and secondary sources. Such sources involve road traffic, domestic heating, wood burning, industries, agriculture, as well as transported long-range pollutants. In addition, the topography and physical layout of built-up areas can affect concentrations of air pollution (Vardoulakis et al., 2003; Baik et al., 2007; Lee et al., 2008). Hence, the reduction of pollutants requires improving scientific understanding of emission sources, atmospheric chemistry, meteorology, as well as the impacts of air pollution on human health and the environment.

Furthermore, the alleviation of atmospheric pollution is complicated by its collective nature and the involvement of a wide range of stakeholders (Schneider and Volkert, 1999; Carter, 2007; Lidskog and Sundqvist, 2011). First, as a collective environmental problem that does not respect any political boundaries, air pollution is dealt with by governments at all levels. A range of policy instruments has been developed to regulate emissions. At the international level, treaties and customary law have been used (Malanczuk, 2002; Kingsbury et al., 2005; Sands and Peel, 2012). Treaties are legally binding agreements between countries that have consented to be bound by the treaty, while customary international law emerges when traditions or customs in certain countries become recognised and are interpreted as international law (Malanczuk, 2002; Sands and Peel, 2012). Treaties can result in conventions, protocols, acts, and declarations (Malanczuk, 2002). The principal international treaty focussing on air pollution is the Convention on Long-Range Transboundary Air Pollution (CLRTAP) formulated by the United Nations Economic Commission for Europe (UN/ECE) in 1979, which was signed by thirty-four States and the European Community (EC) (UNECE, 1979). It is the first legally binding agreement to address air pollution at the international level and has been extended by eight protocols.

The European Union (EU), an organisation committed to economic cooperation and growth currently comprising 28 European countries (Member States) has an extensive environmental policy, which was developed to facilitate a level playing field and to correct the negative environmental externalities generated by economic activity. Two of the city case studies of this research are located in EU Member States, consequently the way in which the EU regulates air quality is central to the thesis. The EU has an array of air quality legislation, much of which was designed to implement international treaty obligations into which the EU and its Member States have entered (European Union, n.d.). Within the EU, one of the most important policy instruments regarding ambient air quality is the Air Quality Directive 2008/50/EC on ambient air quality and cleaner air for Europe. The Directive sets legally binding limits for concentrations of concerned atmospheric pollutant substances for Europe (Council Directive, 2008; Wolff and Perry, 2010; Brunekreef et al., 2015). At the local level, local authorities are responsible for managing local air quality and thereby contributing to the delivery of the national air quality policy goals, but the ways in which they do so varies across states (Longhurst et al., 1996; OECD, 2005; Lutz, 2009; WHO, 2016; Don and Yeo, 2017). Outside the EU, national air quality standards are often established based on WHO guidelines and technological feasibility, economic, political and social considerations (WHO, 2006).

To evaluate the status of air quality and enable informed decision-making, it is necessary to collect data on ambient air pollutants. Monitoring provides a better understanding of the behaviour of pollutants. Measurements can also provide useful inputs for designing and running models and contribute to the prevention and control strategies that can address the adverse impacts of urban pollution on both human health and the natural environment (WHO, 1999; Khopkar, 2007).

Urban air-quality monitoring has been long recognised as a critical component of air quality assessment. It has been adopted in urban areas since the early 1960s to measure and control air pollution (Ott and Eliassen, 1973; WHO, 1977; Asch and Seneca, 1978). Due to mounting concern over air quality and its global impact, in 1973 the WHO initiated a pilot project to strengthen global air-quality monitoring by providing monitoring equipment and training to developing countries. This project led to the Global Environmental Monitoring System for Air Pollution (GEMS/AIR), a joint programme operated with the United Nations Environment Programme (UNEP) in 1975[1] (Mage et al., 1996; WHO, 1999). In 2016, the WHO urban ambient air quality database included data from 103 countries (WHO, 2016). The concentration of several pollutants such as carbon monoxide (CO), nitrogen oxides (NOx), sulphur dioxide (SO_2), particulate matter (PM), and ground level ozone (O_3) are measured regularly (WHO, 2006).

1.2 Motivation and background to the research

Where urban monitoring systems are established, ambient air quality is ideally measured by a network of urban monitors at fixed locations in order to quantify the behaviour of pollutants in both space and time (Mayer, 1999; WHO, 1999). Measurement technologies include different sampling techniques that vary in cost and performance: low-cost passive or active samplers are easy to use but require labour-intensive deployment and careful laboratory analysis; sophisticated automatic analysers are expensive to install and operate but are able to continuously measure air quality concentrations at selected locations[2]; there are also mobile monitoring vehicles that can be employed to complement the automatic

[1] The project ended in 1996. Issues related to global air-quality monitoring are continued under WHO's Healthy Cities programme (WHO, 1999).
[2] The 1999 WHO report estimated a cost range of US $10,000 to $15,000 per analyser (WHO, 1999). Recent studies indicate it costs €5,000 and €30,000 per device (about US $6,000 to $36,000) (Castell et al., 2017), or £5000 and £60,000 (Mead et al., 2013), 'tens of thousands of pounds' (Lewis and Edwards, 2016). In contrast,

network when special measurement surveys are needed (WHO, 1999; Castell et al., 2017). The establishment of monitoring networks depends on legislative requirements as well as the availability of personnel and resources within a specific locale (Larssen et al., 1999; WHO, 1999).

As such, conventional monitoring collects air quality measurements through a number of stations, which do not necessarily cover all locations. To overcome this gap, air quality models, such as dispersion and statistical receptor models, are widely used in order to provide a better understanding of the situation and the changes of concentrations in space and time (Larssen et al., 1999; WHO, 1999; WHO, 2016). Still, there is a concern that the results from such models do not accurately reflect individual exposure due to local factors such as the (microclimate) weather conditions, traffic patterns, and architectural contexts (WHO, 1999; Adams et al., 2001; Steinle et al., 2013; WHO, 2016).

Consequently, public health scientists and atmospheric researchers have sought to develop and apply new sampling approaches in order to better map urban air quality, estimate the personal exposure of citizens and associated health impacts (for example Adams et al., 2001; Devarakonda et al., 2013; Mead et al., 2013; Steinle et al., 2013; Bales et al., 2014; Kumar et al., 2015; Adams and Kanaroglou, 2016; Yu et al., 2016; Schneider et al., 2017). Recently more studies have focused on the evaluation of the technical performance of commercial low-cost sensors (see Lewis et al., 2016; Castell et al., 2017; Kelly et al., 2017; Rai et al., 2017). New monitoring tools are also increasingly employed in citizen science research (for example, Hasenfratz et al., 2012; Snyder et al., 2013; Bales et al., 2014). At the same time, as technology has developed, more commercial products have come on the market. These low-cost air quality technologies are smaller, lighter, portable, can be handheld and are even wearable[3]. Moreover, the results are often available via smartphone applications so that air quality readings are instant and accessible on different platforms to the users. New air-quality monitoring technologies are affordable and available to a much wider range of consumers.

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the low-cost sensing component alone, i.e., OEM sensors, is about US $10s (Rai et al., 2017). For instance, the PMS 1003/3003 particle counter costs US $35 (Kelly et al., 2017). The consumer monitor costs a few US $100 (Kumar et al., 2015; Rai et al., 2017).

[3] Examples include Dylos Air Quality Monitor (www.dylosproducts.com), Laser Egg (www.kaiterra.com), Breeze air-quality sensors (www.breeze-technologies.de), Air Quality Egg (www.airqualityegg.wickeddevice.com), the AirCasting sensors (www.aircasting.org).

New air-quality monitoring practices have led to significant changes in the context of usage, such as the location, time and social identity of the users, compared to existing monitoring networks. Without understanding the social context, the needs of end-users and the ways in which information can be used, it is hard to evaluate the usability of the new monitoring tools. By emphasising end-users' involvement and their needs we can address some important questions raised by the development of new technologies. For instance, who are the primary end-users of innovative monitoring tools? How can we explain the choices made by end-users? How can the measurements generated by novel devices inform and shape air pollution abatement in cities? Can new technologies improve established air quality monitoring techniques? How are air quality practices used in different urban settings? What is the social-political scope for a new monitoring paradigm?

Yet, despite the widespread scientific projects focusing on technical issues and the growing interest of concerned citizens, social studies that shed light on and evaluate the context of and human factors in air-quality sensor application are limited (Hubbell et al., 2018). There remain gaps in the conceptualisation of end-users' involvement in emerging new air-quality monitoring practice and existing monitoring networks. There is also a need to have more empirical studies to investigate the function of air-quality monitoring and the rationale behind end-users' perceptions in distinct urban settings. By collecting original data and investigating air quality monitoring practices in three distinct cities from end-users' perspectives, this research addresses this knowledge gap and contributes to academic discussion of the use of new monitoring tools.

1.3 Research aim and research questions

This research aims to establish the needs of end-users involved in urban air-quality monitoring by exploring the social-political scope for the adoption of new air-quality monitoring practice in cities. Therefore, distinct cities that vary in characteristics, such as size, location, cultural, history, and experience with air pollution, are of interest. In order to provide a deeper elucidation of new air quality monitoring practice in diverse city contexts, this project adopts a case study approach (Bryman, 2012). The cross-national cases include three countries where official air-quality monitoring-networks have been well established and managed. They are:

York, England, United Kingdom. York is a typical European city which has a relatively small geographic area and population but a rich historic and natural heritage. York is a popular tourist destination. It has on-going issues with air quality, most notably it struggles to meet annual NO_2 air quality standard.

Berlin, Germany. Berlin is a large European city that has successfully achieved some environmental targets and has an ambitious sustainable development agenda. Yet, the city has difficulties in attaining some air quality objectives.

Seoul, South Korea. With more than 10 million residents, Seoul is a megacity, which has experienced rapid urban development and is seeking to develop a sustainable future while facing various environmental challenges. The study in Seoul provides useful information on understanding the challenges and importance of air pollution monitoring in megacities.

The following figure illustrates the location of the three cities in this study.

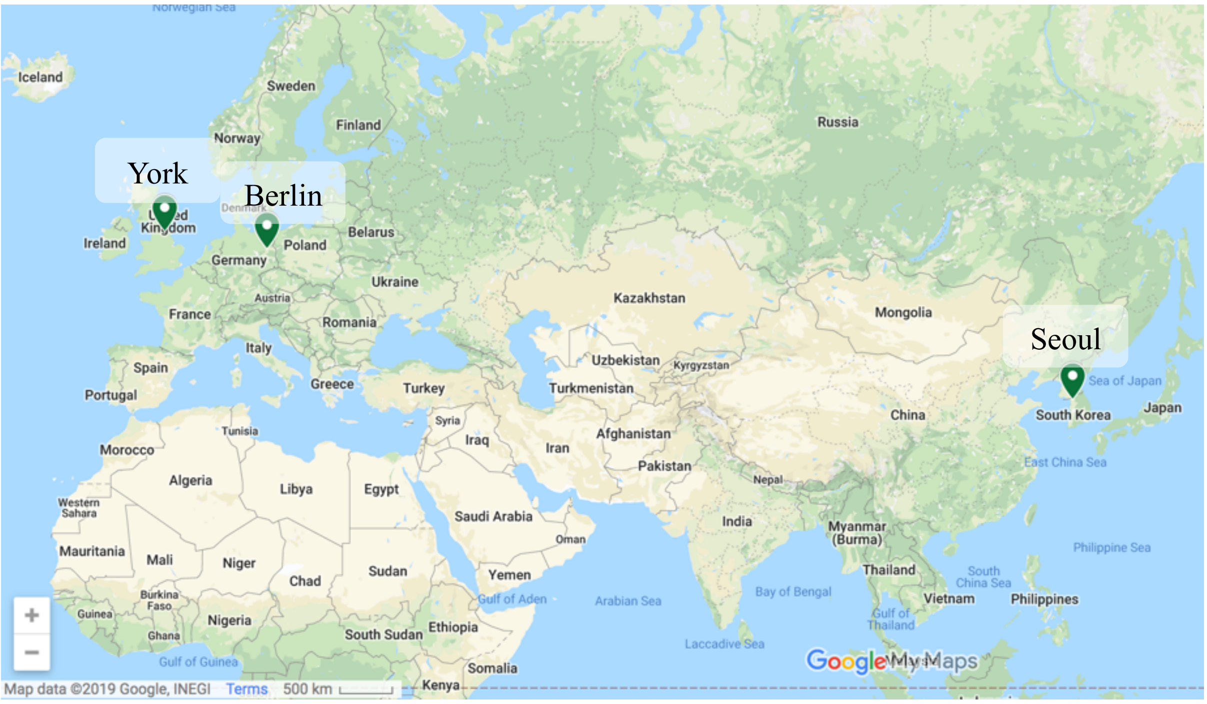

Figure 1- 1 Location of cities included in this research, made with Google My Maps (Google Maps, 2019)

The research therefore provides transnational empirical data and contributes to the knowledge on understanding urban air quality issues by exploring heterogeneous contextual factors that affect end-users' opinions about the use of emerging air quality monitors for cities. Yet, it should be noted that the analyses undertaken in this research do not provide unambiguous and universal explanations of the perceptions of end-users on emerging air-quality monitoring paradigms. Instead, this study uses the three case studies to argue that contextual factors need to be considered in analysing the use of new air-quality monitoring technologies.

In order to obtain an initial overview of the political context of urban air-quality monitoring, my research involved a mapping exercise to determine the statutory requirements for air-quality monitoring and management in the three cities (York, Berlin, Seoul). According to the status quo, governments were arguably the most obvious end-users of air-quality monitoring data. Still, questions remain regarding whether new forms of data from novel technologies are of interest to governments, who the other end-users of emerging practice are and what their views are on the use of new air quality monitors. Hence, to establish end-user needs of air-quality monitoring, my study addresses the following research questions:

Question one: What is the meaning of an end-user in the context of urban air-quality monitoring?

Question two: What data do end-users need and why?

Question three: What is the role of emerging monitoring practice in urban air quality management?

Question four: What are the factors shaping the deployment of new air pollution monitoring technologies in the three cities?

Question five: How can we best ensure that established practices are updated to allow for the adoption of emerging technologies?

1.4 Significance and contribution of the study

This study seeks to contribute to the increasingly popular interdisciplinary field of emerging low-cost air-quality sensors (see, for example, Adams et al., 2001; Yearley et al., 2003; Hasenfratz et al., 2012; Steinle et al., 2013; Bales et al., 2014; Kumar et al., 2015; Adams and Kanaroglou, 2016; Yu et al., 2016; Lewis et al., 2016; Castell et al., 2017; Kelly et al., 2017; Rai et al., 2017; Schneider et al., 2017). This burgeoning field struggles to keep pace with technological advancements on the ground and encompasses studies on air quality management, technological innovation and citizen science studies. This contribution is firmly situated at the intersection of these topics. This research bridges social science methods with topics from technology development and natural sciences regarding air-quality monitoring by conceptualising end-user stakeholders. Through collecting and analysing original primary interview and documentary data in three cross-national cases, the study identified end-users of new air quality monitors and explored the context of usage from a multi-dimensional perspective. While existing studies focus more on the technical performance of innovative monitors or the development of new techniques (see, for example, Adams et al., 2001; Hasenfratz et al., 2012; Bales et al., 2014; Jovašević-Stojanović et al., 2015; Lewis et al., 2016; Castell et al., 2017; Kelly et al., 2017; Rai et al., 2017), this research investigated the perceptions of users. These wider social-political understandings have not yet been adequately investigated, not least because the emergence of these technologies is so novel.

This study will inform a range of stakeholders who are interested in the new emerging air-quality monitoring paradigm through perceptions of diverse end-user groups. The research defines the term end-user and has collected empirical evidence of end-user views of low-cost air quality monitors. The thesis argues that social and human factors need to be taken into account when evaluating the usability of a variety of monitoring strategies. The findings provide a springboard for future studies to investigate why and how a wide range of technical features are or can be used by different end-user groups in practice.

1.5 Scope of the study

This research focuses on emerging technologies for measuring ambient air quality in three cities. The study investigates governance regimes with respect to urban air quality as well as implications of new monitoring practice upon the management of air quality.

This research concerns ambient air-quality monitoring. Although portable devices make measuring indoor air quality possible, current laws and regulations regarding indoor air-quality monitoring are yet to be developed in many countries. Therefore, there is no baseline to examine the differences between existing practice and new ways of monitoring. Furthermore, since ambient air-quality monitoring-networks have been in operation for decades in many developed countries including those in this study, more data are available to conduct the analysis.

Additionally, this study is not about air quality management, which involves more activities than monitoring. But as an imperative tool serving urban air quality management, it was anticipated that the discussion on issues other than monitoring, e.g., emission inventory, transport management, vehicle technology, would be inevitable. As such, the findings provide useful insights on how air quality policies are implemented and are affected by diverse contextual factors. Nonetheless, takes as its focus air-quality monitoring and the effects of various monitoring practices on air quality management.

The cities were chosen as an attempt to investigate the research topic in distinct cities worldwide and this study is part of a large European research project, Cutting-Edge Approaches for Pollution Assessment in Cities (CAPACITIE). The parent project was a Marie Curie Initial Training Network, funded by the European Commission within the Seventh Framework Programme which had collaborators from Berlin and Seoul. As such, it was expected that the CAPACITIE project as a platform of collaboration would benefit this study by providing higher resource availability and accessibility for carrying out research interviews.

Lastly, this research is an interdisciplinary study. It is closely related to many academic disciplines, including but not limited to environmental politics, environmental management, environmental psychology, environmental technology, and atmospheric science.

Established air-quality monitoring practice

Existing air-quality monitoring-networks are often operated by governmental organisations and are primarily used for checking compliance and decision-making. An established monitoring practice also involves information-sharing facilities, such as website or media broadcasting. In this dissertation, it is the term is also taken to mean traditional monitoring, statutory monitoring, routine monitoring, official monitoring, compliance monitoring and the traditional paradigm. The instruments and sampling methods used are 'reference methods' prescribed in official air quality policies. Established monitoring practice also involves existing forms of air quality information dissemination.

Emerging air-quality monitoring practice and new monitoring technology

These are the counterparts to established monitoring practice. In this thesis, these terms refer to air-quality monitoring activities employing new monitoring technologies. New forms of monitoring are platforms covering both emerging monitoring devices and associated information-sharing infrastructure. Such tools are advanced by electronical engineering and data communication technologies. They are often small, low-cost, portable, easy to use, light and often supported by smartphone applications. They can be used as a single sampling point or can be integrated into a network. There are also devices that can be fixed at selected places to create a community monitoring network similar to the regulatory stations. But such devices are not considered as reference methods. In the broadest sense, it means any measurement using devices that are not prescribed in air quality legislation. The terminology also captures new monitoring practice, new paradigm, non-regulatory monitoring and non-compliance monitoring using new air-quality monitoring sensors.

Particulate matter (PM2.5 and PM10)

Particulate matter consists of a complex mixture of solid particles and liquid droplets of various sizes in the atmosphere (WHO, 2006; Royal College of Physicians, 2016). They can be formed either primarily or secondarily in the atmosphere through chemical reactions (secondary formation). The precursors (origins) of secondary PM include SO_2, NOx and VOCs (volatile organic compounds) and the formation of secondary aerosol can take days (AQEG, 2005). As such, PM can travel long distances through the process of long-range transport (WHO, 2006). It contains diverse components which may have different health impacts (WHO, 2006; Royal College of Physicians, 2016).

In compliance management, particulate matter is generally classified by its aerodynamic diameter, corresponding to a size of less than 10μm (PM10) or 2.5μm (PM2.5). PM2.5, or fine particles, are an important human health risk indicator of particulate pollution (WHO, 2006).

Nitrogen dioxide (NO_2) and oxides of nitrogen (NOx)

NO_2 is one of a group of gaseous compounds known as oxides of nitrogen or nitrogen oxides (NOx). Emissions of NOx are primarily from anthropogenic sources (WHO, 2006). The pollutant of great health concern among other chemical species of NOx is NO_2. The gas is reddish brown and toxic, which is used as the indicator for the larger group of the mixture as a whole (ibid.). NO_2 can be produced directly in the combustion process of fuel, but the majority of NO_2 is a secondary product through the oxidation of nitric oxide (NO). The oxidation process can happen very fast by reaction with atmospheric ozone (O_3) (WHO, 2006; Royal College of Physicians, 2016). NO_2 is an important trace gas. It is oxidised in air to form nitric acid (HNO_3), which can further react with other chemical compounds leading to the formation of nitrate particles, a secondary particulate matter (WHO, 2006).

1.6 Thesis overview

This thesis contains eight chapters, which include four discrete sections: introduction and theoretical background, methodology, analyses and discussions of empirical data, finally the conclusion (see Figure 1- 2).

Chapter Two reviews the definition of end-user and stakeholder in order to conceptualise end-user to fit the research context. Focusing on the involvement of end-users, Chapter Two then proposes an end-user stakeholder concept.

Chapter Three presents the methodology that guides the research process, which is underpinned by a qualitative case study design, based on grounded theory. Semi-structured interviews were used to gain the perceptions of stakeholders in different urban settings.

Chapter Four to Chapter Seven present the analysis and findings derived from qualitative data collected in the three cities. The thematic concepts developed from the analysis of York study are employed as orienting themes in the analyses of Berlin and Seoul. Five themes containing various topics that are applicable to the three cities are developed. They are: awareness and willingness, state and progress, power and influence, responsibility and technological innovation. These themes emerged from the qualitative analysis of York, Berlin and Seoul. The findings of each are discussed in relation to the related literature in Chapter Seven, such as environmental politics, air quality management, environmental risk perception, and technological innovation. The key themes of this study confirm the findings of existing literature to a great extent and extend the discussion to the field of emerging low-cost air-quality monitoring in cities by providing empirical evidence collected in three cities. The analysis indicated that a low level of public and political awareness and willingness is a common threat to urban air quality improvements despite the differences between the three cities. Still, there appears to be a gap between awareness and behavioural responses. The discussion highlights that knowledge of air pollution alone is not sufficient to motivate environmentally-responsible behaviour change.

The final Chapter Eight summarises the results and identifies the research contributions made by the thesis and the ways its findings can be mobilised to shape practice. This chapter also reviews the research process and reflects on its limitations. Directions for future enquiries are also recommended.

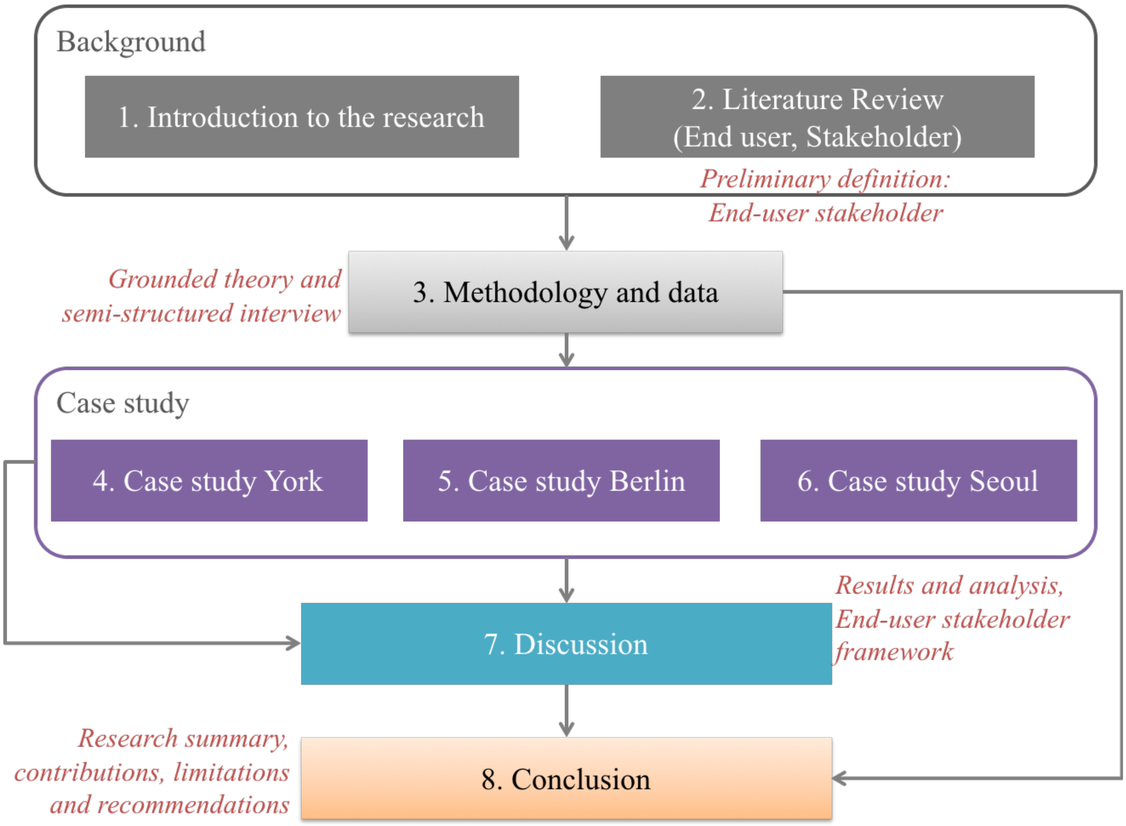

Figure 1- 2 Structure of the thesis

Chapter Two Literature review: end-user and stakeholder theory

2.0 Introduction

This chapter seeks to define the term end-user within the research context of urban air-quality monitoring by visiting the literature on end-users and stakeholder theory. On one hand, without knowing who the end-users of data are and what their purposes of utilisation are, it is not feasible to evaluate the usability of emerging low-cost monitors and likely impacts of deploying these sensors on air quality management on the ground. On the other hand, when the term end-user is discussed in a technological development setting, there is often a lack of clarity about what it means. The term is rarely defined and is widely used interchangeably with user (Jaspers, 2003; Ghanem et al., 2004; Maisonneuve et al., 2009; Murty et al., 2008). It is clear that the term end-user is one way of expressing user, but for this research it is left open whether this is the difference between technology users, data users, and potential information recipients of air quality measurements. Furthermore, is there any difference between governmental and societal actors? Are the end-users equally influential in existing and new air-quality monitoring practices? What factors would affect their decisions with respect to the choice of monitors? Without specification and justification, who the end-users are, their roles, and how they have involved in the development and deployment of new monitoring technologies remain open to questions.

Currently, there is no theoretical method available for identifying and analysing the target end-user group(s) in urban air-quality monitoring. By contrast, the concept of '*stakeholder*' is widely acknowledged and has been used in many disciplines. This term provides a useful approach for recognising interacting actors and their relationships within a network of interest. Therefore, stakeholder theory is used to identify those who share an interest in air pollution monitoring, what benefits they may get from the measurements and to determine what influences they may have.

Consequently, this chapter refines and clarifies the term end-user by incorporating some of the conceptual toolkit used in the stakeholder literature in order to provide a working definition of the '*end-user stakeholder*' to underpin the analyses of the use of new air-quality monitoring technologies in three study cities (York, Berlin, Seoul).

The chapter proceeds with a review of the end-user concept in the computer science literature, focusing on understanding the boundary of the term that limits the user groups and the relationships between end-users and other actors so that specific end-user groups can be recognised. In order to identify some common characteristics that can underpin the definition of end-user used in this study, the literature from other disciplines, such as social studies and innovation adoption, are also discussed. Sequentially, the chapter presents a review of the stakeholder concept. Since the use of new air-quality sensors is an interdisciplinary research topic, this review is engaged with several relevant research fields. These areas include business and corporate management in which the stakeholder concept was originally defined. The other fields involve public administration, environmental studies as well as science and technology development. The stakeholder concept is used to help to outline the relational nature of end-users, providing a benchmark for those aspects that should be included when analysing the role of an end-user with respect to the application of new air quality monitors.

It should be noted that end-users are also stakeholders, though both terms are context (subject) dependent, i.e., end-user/stakeholder of what. The term stakeholder, when used in relation to urban air-quality monitoring, refers to a more extensive network of which end-users are a part. While user emphases the practical aspect of human-technical product interfaces, the term '*stakeholder'* also embraces a lens of examining how the power, responsibility, benefits and costs are distributed among the users. This wider conceptualisation is helpful for understanding not only the technical aspects but also the social and political challenges that technology adoption can raise. Due to the scope of the project and the resource availability, this research focuses on studying '*end-user stakeholders*' instead of performing a complete stakeholder analysis, trying to illustrate the relations between tiers of stakeholder end-users. This chapter provides an introduction to the specific context in the study cities (York, Berlin, Seoul), and serves as a foundation for exploring the potential tensions that emerged between end-user needs, formal environmental targets, and the environmental willingness of a wider society.

2.1 What and who is an end-user?

2.1.1 The use of low-cost air quality monitors

Air quality and public health researchers have paid attention to the development and utilisation of low-cost air-quality sensors in various ways. First, a range of research projects has focused on the design and experiments of different mobile sensing platforms to measure various atmospheric pollutants. For instance, Hasenfratz et al. (2012) introduced a measurement system - GasMobile, which integrated a low-cost ozone sensor with a smartphone application. The researchers sought to involve '*the average citizen*' in the measurement of ozone pollution (ibid.). Devarakonda et al. (2013) proposed a mobile pollution-sensing schema that comprises a public transportation sensing model and a personal one for *users* to measure carbon monoxide and particulate matter in real-time. The sensing systems also include smartphone applications and web-based servers (ibid.). Bales et al. (2014) developed the CitiSense system, which consists of a wearable mobile phone component that includes six sensors, and a web-based information-sharing portal. The mobile monitoring unit measures carbon monoxide, nitrogen dioxide, ozone, temperature, barometric pressure as well as humidity. In order to analyse the effect of receiving extra air quality data generated by the CitiSense system on individual behaviour, the sensing system was used in a citizen science *user* study which recruited 16 participants. As such, the team designed and applied a mobile air quality sensing system for '*novice users*' with real-time exposure information (ibid.).

There are also studies that have employed a variety of sensing systems as tools in research. Mead et al. (2013) demonstrated the potential of low-cost air-quality sensors by deploying sensor units (nodes) in a highly-density network and concluded that such sensor networks may provide feasible measurement methods for the *'inclusion in air-quality monitoring and regulation, source attribution and human exposure studies'*. Steinle et al. (2013) reviewed existing methods for evaluating personal exposure and proposed a new model for the assessment of individual exposure to air pollution by using mobile air quality monitors. Other examples see also Hasenfratz et al. (2012), Castell et al. (2013), Snyder et al. (2013), Bales et al. (2014), Yu et al. (2016), Adams and Kanaroglou (2016), and Schneider et al. (2017).

Another research area concerns the technical performance and usability of these low-cost sensors. For instance, Jovašević-Stojanović et al. (2015) tested some commercial PM sensors and concluded the potential for '*use in a citizen-based observatory network*'. Several other studies have evaluated data quality in laboratory or real-world conditions (See Lewis et al., 2016; Castell et al., 2017; Kelly et al., 2017; Rai et al., 2017). These efforts are largely driven by the diverse features of low-cost sensors and the intention of providing '*end-users*' a better understanding of the capabilities and limitations of such new air-quality sensors (Kumar et al., 2015; Lewis and Edwards, 2016; Castell et al., 2017; Rai et al., 2017).

Nonetheless, while emphasising the potential of using new air quality monitors and the importance of considering end-user perspectives, existing studies did not specify the meaning of users or end-users. Technology providers tend to project an imagined user group and anticipate their responses to the information received from the deployed device (Reed, 2017). When deploying low-cost sensors in research projects, the monitors are an object of study, therefore, the community of researchers is the user group. Yet, when developing and evaluating the performance of a range of low-cost sensors, the general public seems to be the user. Lack of clarity about the identification of end-user groups makes it infeasible to establish the needs of end-users and complicates the evaluation of the usability of air-quality sensors.

2.1.2 End-users in computer studies

Emerging air quality monitors are technically advanced by electronical engineering and associated software which are operated on devices that have processing units to carry out operations. This collection of processes is rooted in computer studies, that is, therefore, a useful starting point for understanding the meaning of end-user in the adoption of new urban air-quality monitoring technologies. In this dissertation, '*computer studies*' is applied as an umbrella term encompasses computer science (CS), computer engineering (CE), information technology (IT), and other related areas.

The term '*end-user*' implies that an end-user is at least part of a user group, if not interchangeably. One of the early attempts to specify end-users in literature is provided by the End-user Facility Task Group of the CODASYL[4] Systems Committee (Lefkovits, 1976), which described end-users as '*a sizeable subset of the users of data processing equipment and its output'* (p. 3). The intention of this description was to specify the end-users of End-user Facility, as a separation from the wider range of people in the data-processing industry where the terms '*user*' and '*end-user*' are used interchangeably to refer to a non-data processing professional. Hence in this context, the term was not used to refer to any non-professional, but rather to someone who is proficient in her job but may need the data-processing product, End-user Facility, to support her work in order to make her more competent (ibid.). In addition, end-users' relationships to the data-processing system and the information obtained might be at different levels due to different job functions. Three end-user categories were therefore developed, including '*indirect end-users*', '*intermediate end-users*', and '*direct end-users*' (Rockart and Flannery, 1983, Cotterman and Kumar, 1989; Martin, 1990; Amoroso, 1992). In practice end-user groups can be understood in the following scenario: the corporate executive is asking the financial manager for financial information on the business. In order to report that, the financial manager commends the specialist to generate certain figures by using software, and then provides the results to the executive. Among them, the specialist who works directly with the data processing software is the direct end-user of the analytical tool, the financial manager who specifies the request is the intermediate end-user and the executive for whom the processing task was undertaken is the indirect end-user.

Yet how the end-users are contacted with the system is just one aspect describing how users are involved in human-computer interfaces, their knowledge or skills about the product might be another. One prominent phenomenon, end-user computing (EUC), emerged in the early 1980s after the introduction of portable computers, and the boundary between users and professionals became blurred as people who used the systems increasingly became developers (McLean, 1979; Rockart and Flannery, 1983; Doll and Torkzadeh, 1988; Brancheau and Brown, 1993; Torkzadeh and Doll, 1993). McLean (1979) suggested that the term end-user simply refers to the user of computer-based information system

[4] Conference on Data Systems Languages, it was a voluntary consortium with members from different sectors who were involved in data processing activity, formed in 1959 by the US Department of Defence to guide the development of a standard programming language. (Source: http://oxfordindex.oup.com/view/10.1093/oi/authority.20110803095621302, accessed: 11 September 2015)

because the analyst or programmer plays the role of '*middle man*', who conveys the user's requirements to the system designer. He then classified the users, or end-users, into two groups primarily based on the developing skills of users. They are data processing (DP) professionals who write code for others, and data processing users that includes DP amateurs who write code for themselves and non-DP trained users who have no programming knowledge at all and use code written by others only (McLean, 1979). Built on the earlier research, Rockart and Flannery (1983) extended the categories to six breaking down the '*direct*' category in the CODASYL report while taking into account the position, responsibility, and the programming skills of the user (see Box 1). Whereas Leithelser and Wetherbe (1986) argued that due to the behaviour variations, such as lack of data documentation, or backup management plan, end-users may bring in risks when they interact with computer tools. It is therefore important to consider the risk factor when defining the end-users and managing the EUC process. In order to profile different end-users and assess the risks associated, Cotterman and Kumar (1989) considered the end-users as '*any organisational unit or person who has an interaction with the computer-based information system as a consumer or producer/consumer of information*'. The authors then developed a taxonomy to assist the classification of end-users in computing activities and assessment of risks by drawing three dimensions including operation, development and control of the information system.

Similar discussions also found in end-user development (EUD) or end-user programming (EUP) literature, which is a field of computer studies that focuses on the process of enabling end-users to control and to develop applications. Lieberman et al. (2006) stated that the distinction between users and developers is not appropriate anymore, as an increasing population is getting familiar with computer software and has the needs to have tailored applications by themselves. They, therefore, suggested that the purpose of the future intelligent system should be '*easy to develop*' and everyone can be a developer, no matter whether or not you have the programming skills. The end-user in that context is simply understood as '*users of software systems, who are acting as non-professional software developers*' (ibid.). Ko et al. (2011) stated that '*an end-user is simply any computer user*' (p. 21:4), further explaining that the word *end* can be a concept from the economics and business discipline as a software can be purchased by intermediaries, who are not the actual user. In this case, a skilled developer who writes codes to achieve her specific goal instead of programming for a wider group of users is also considered as an end-user. Here the definition departs from the purpose of programming, instead of the means of interaction with computer systems, dependency, or skills as the above. End-user is defined as a contrast to professional programmer only.

Box 1 Six categories of end-user by Rockart and Flannery (1983)

- *Non-programming end-users*, who use the software provided by others to get the data and have no programming skill nor need to generate a report of the data they get.
- *Command level users*, who have basic understanding of the database and the software, and they are able to produce or apply limited set of commands to get the outputs according to their own needs.
- *End-user programmers*, who are able to develop applications by using computing language to meet their own needs
- *Functional support personnel*, who write programs for other end-users in their own functional area.
- *End-user computing support personnel*, who are able to not only perform programming activities, but also know the languages of the other end-users using and provide support when need arises, which is their primary job function.
- DP programmers, who are the experts developing software for others in the organisation by using the end-user language, they are acting as internal contracted programmers

All the attempts recognise that an end-user is an individual who interacts with a computer-aided system. It is a widely used term used in the field of human-computer interaction which considers the evaluation of usability and design for purpose regarding a software (Lieberman et al., 2006). Thus, broadly speaking, an end-user is simply a user of a product. In practice it might be the user of personal computer (Rockart and Flannery, 1983; Ko et al., 2011), a specific software application (Brancheau and Wetherbe, 1990; Maraun et al., 2010), or other information-technology based product, for instance a network system or mobile application (Heinzelman et al., 2000; Pedersen et al., 2002). Thus, the end-user groups can be specified based on different criteria that can be but not limited to the intention or purpose of the end-user applying the product, the job category of end-users, knowledge or skills of the person on the system, the dependency or frequency of using the application, as well as control levels of the tool and its output. The specification is made, directly or indirectly, in various research streams in order to fit individual research needs.

2.1.3 End-user in other studies related to the use of pollution monitoring data

The deployment of innovative air-quality monitoring technologies is not only about analytical instruments or software, it also relates to political and social issues associated with the adoption of technical innovation. Therefore, it is necessary to investigate the understanding of end-users in technology adoption studies as well as in analysing social aspects of research and innovation.

The term end-user is commonly used comparably as the user in the broadest sense in the studies of technology development and adoption. Before the emergence of computing research in the 1970s, the term end-user was used in mobile communication products (Beers Jr, 1957). It was used to label the users of vehicular communications equipment, as different to the device designers. Douthwaite et al. (2001) analysed the role of farmers (end-users) in the adoption of new technologies in Asian farming systems and described end-users as '*opposed to researchers*'. A later study examined the role of end-users in the Dutch agriculture research and development (R&D) process applied the same concept that the farmer is the end-user of agricultural research and innovation (Klerkx and Leeuwis, 2008). Similarly, Pedersen et al. (2002) considered an end-user as a user of mobile commerce services, in order to separate the user from operators, service providers and application developers of the technology. At the same time, the complexity of end-user was illustrated, as the technology user is also a consumer and a network member at the same time (ibid.). It is, therefore, important to identify the unique context of a product when identifying or investigating the needs of end-users.

The general perceptions are also found in social studies, where an end-user is understood as a user of certain product or service and can be classified into subgroups based on different attributes or characteristics of the person. When analysing the effects of society involvement on the UK research funding system in the late 1990s, Maclean et al. (1998) classified the users or beneficiaries of research into different groups. In one of the dimensions, the researchers compared end-users with intermediate users. They termed end-user as people '*who incorporate the results from research directly into an innovation*', while the intermediate users are people '*who in some way transform the results of research and add value to them before passing them on to an end-user (or to another intermediate user)*' (Maclean et al., 1998). Here the end-user is the ultimate data user of scientific research who is aiming at transferring the knowledge into innovative product rather than adding additional expertise. This definition limits the end-user to the direct end-user only as what is included in the computer science studies, see (Lefkovits, 1976; Rockart and Flannery, 1983; Ko et al., 2011).

Though the researchers may have different approaches to classifying end-users, the important role of an end-user in technology development and adoption has been recognised. In computer studies, the attempts of specifying end-users seek to provide a tailored system that suits the needs of a particular end-user class (for instance Lefkovits, 1976; Doll and Torkzadeh, 1988; Cotterman and Kumar, 1989; Pedersen et al., 2002; Lieberman et al., 2006). In agricultural R&D studies, the participation and interactions of end-users are included as one of the influencing factors in the technology deployment process apart from institutional and political aspects (Douthwaite et al., 2001; Klerkx and Leeuwis, 2008). End-user involvement could benefit the modification of the product and improve the performance in line with the real condition, therefore contributing to the impacts of application (Douthwaite et al., 2001). A similar example demonstrating the influencing role of users is in the automotive industry - the newly released Chevy Volt for 2016 at the Detroit Auto Show from General Motors. Besides the engineering improvements, for instance, the battery weight, energy capacity, and electric power range, the redesign is also influenced by the inputs from customers who purchased the previous generation's plug-in vehicle (Burden and Shepardson, 2014; General Motors, 2015). Another example reveals the influence or power of end-users is the Google Ara modular smartphone (Google, 2016a). It enlarges the freedom of an end-user and includes individual customers in the design by providing a semi- crafted smartphone. So that the smartphone users can choose and swap the modules which fit the peculiar needs the best.

Overall then it is reasonable to see that there is a shared understanding of the term across disciplines that end-user is another way of saying the ultimate user of a certain product. End-user emphasises the position of the user, as opposed to the researchers, designers, developers, providers or others involved in the delivery of application, being the individuals for whom the product is served for. She may not be equipped with the same expertise as the product providers, but her involvement and sustained participation could largely affect the technology modification and ultimately, the acceptance of the technology.

2.1.4 Identified gaps in the extant end-user literature

The long-time adoption of the end-user concept in computer studies and its use in other disciplines imply that there is no clear-cut definition of end-user, and it is not a single entity but can involve several clusters. Moreover, there is no fundamental framework to distinguish the tiers of end-users or to address the relations between different types of end-users in other disciplines. In the conceptualisation of EUC, the past studies show that there are several types of end-user. The user's position, capability of accessing and developing the applications, the way of interacting with the technologies all affect determining the end-user type. Thus, whilst the EUC research considers several factors for specifying end-users, such as the three dimensions of operation, development, and control in the User Cube (Cotterman and Kumar, 1989), there is no commonly accepted classification scheme.

Besides, even though past studies have recognised the role of end-users is changing and the importance of participatory design, most of the definitions or applications do not pay attention to the network nature of end-users in technological development and implementation. Yet these networks are important to the commercialisation and application of new techniques. For this research, as more novel devices are portable and are able to be incorporated with personal devices such as smartphones and tablets, even collecting personal data, issues regarding customised features and data management need to be addressed (Palen and Dourish, 2003). In addition, the user's choices could largely affect the market share of the product and final deployment in real life. An approach that is able to outline the influence and illustrate the relation nature of end-users would be helpful.

To summarise, end-user is, therefore, a classic term used as a tradition or even a common title that emerged from the human-machine interactions meaning anyone as opposed to professionals for whom the technology is developed and delivered. And it has been studied and applied across disciplines. Yet it is a complex terminology that can be interpreted and analysed in multiple aspects depending on the purpose and context of research. Therefore, an approach to identify the end-user in specific scope is needed.

The limitations of end-user concept run contrary to the notion of stakeholder, which has been well established and applied in various fields and provides an approach to identify key stakeholders, their interests, power, and possible positions in the future. Therefore, this research uses the stakeholder concept to further refine and classify the nature and role of end-users in order to identify who these individuals are and how they participate in air quality monitoring in the three case-study study cities.

2.2 Stakeholder concept in literature

The stakeholder concept can be interpreted from both theoretical and practical perspectives. Theoretically, '*stakeholder theory*' is a concept from corporate management studies and business ethics that argues the success of one organisation or achieving an objective is dependent on a set of relationships between the business and both internal and external actors, as well as the strategy of managing them (Donaldson and Preston, 1995; Freeman and McVea, 2001; Freeman, 2010; Parmar et al., 2010). Several variations of the term, such as '*stakeholder framework*' (Clarkson, 1995; Mitchell et al., 1997; Freeman and McVea, 2001), '*stakeholder management*' (Earl and Clift, 1999; Reed, 1999; Freeman and McVea, 2001; Buysse and Verbeke, 2003), and '*stakeholder thinking*' (Carroll and Näsi, 1997; Agle et al., 2008; Parmar et al., 2010) are also widely used.

Practically, the interpretation of the concept comes in the form of '*stakeholder analysis*', which attempts to understand and identify the impacts of stakeholder involvement in an organisation and the process of achieving an objective by employing analytic methods. References can be also found as '*stakeholder method*' or '*stakeholder approach*' (Goodpaster, 1991; Clarkson, 1995; Grimble and Wellard, 1997; Brugha and Varvasovszky, 2000; Freeman, 2010), or stakeholder *'impact', 'influence',* and *'values'* (Bourne and Walker, 2005; Mathur et al., 2008) in the literature. Though the term is not the same, it is commonly recognised that the process of identifying stakeholders, or *'influencers', 'claimants', 'publics'*, *'constituencies'*, analysing the interactions between them and the system that they are involved in is an effective way of evaluating the interest (stake) of different actors (individuals, groups and organisations), and determining their relevance and impact in a particular setting (Freeman and Reed, 1983; Clarkson, 1995; Mitchell et al., 1997; Reed et al., 2009). To put the aspects together, stakeholder theory provides a strategic framework that consistently reflects the relationships and changes in the business environment by performing certain analytic methods. The different terms reflect the complex roots of the theory that include business management, system and organisational theory as well as corporate social responsibility. The following sections present the development of the concept and its applications in various disciplines.

2.2.1 History of the stakeholder theory and debates

The development of the stakeholder concept has been widely discussed in the business management literature. Preston and Sapienza (1990) pointed out that the concept, if not the term itself, was originally articulated within the corporate management field in the 1930s. It was formally presented by Professor Dodd in the Harvard Law Review when discussing the ethical duties of business (Dodd, 1932). Professor Dodd (1932) quoted the conceptions of General Electric executives and some business analysts who collectively identified four interest groups, the employees, the consumers, the general public, and the stockholders. Most scholars credit Freeman's landmark publication, *Strategic Management: A Stakeholder Approach (1984)*, for the popularity of stakeholder idea (Clarkson, 1995; Mitchell et al., 1997; Brugha and Varvasovszky, 2000; Agle et al., 2008; Reed et al., 2009; Parmar et al., 2010). In the book, Freeman traced the concept back to the Stanford Research Institute (now SRI International) in the 1960s where the actual word '*stakeholder*' appeared in the management literature for the first time (cited in Clarkson, 1995; Freeman and McVea, 2001; Freeman, 2010). The definition of stakeholder in the work is presented as '*any group or individual who can affect or is affected by the achievement of the organisation's objective'* (Freeman 1984: 46), which has been widely cited since then (cited in Mitchell et al., 1997; Grimble, 1998; Brugha and Varvasovszky, 2000; Freeman et al., 2004; Reed et al., 2009; Freeman, 2010)[5]

Freeman's stakeholder interpretation provided a solid basis for the subsequent studies that further elaborated on the theory, but it also augured wide-ranging debates on the definition and the theory among scholars, stakeholder theorists and practitioners, predominantly in areas related to business management, such as strategic management, business ethics, finance, and even economics (Donaldson and Preston, 1995; Sternberg, 1996; Gamble and Kelly, 2001; Jensen, 2001; Friedman and Miles, 2002;

[5] The paper was written in 1982, published in 1984 (Freeman, 2004).

Cragg, 2002; Parmar et al., 2010; Carroll and Buchholtz, 2014). Clarkson (1995) recognised that the definition can considerably differ in scope, and by contrast to Freeman, he defined the term from a narrower point of view which focuses upon the importance or influence of a certain person to the corporation's survival. Mitchell et al. (1997) commented that Freeman's definition is one of the broadest terms, and that it can basically include anyone. Consequently, Mitchell et al. (1997) eschew using a simple definition, but rather classify all stakeholders according to three attributes: *power, legitimacy and urgency*, drawing attention to the stakeholders' salience, and proposing a dynamic identification model based on the combinations of the three attributes.

Noticing the long-term development and the theory dimensions behind the notion, it is simply not possible to comprehensively review the extensive references on the evolution of stakeholder concept, and how it affects the corporations, organisations, or society in general here. The arguments and diverse perspectives are discussed in detail elsewhere (e.g., Freeman and Reed, 1983; Hill and Jones, 1992; Clarkson, 1995; Donaldson and Preston, 1995; Mitchell et al., 1997; Gamble and Kelly, 2001; Freeman and Phillips, 2002; Phillips, 2003; Freeman, 2004; Freeman et al., 2004; Laplume et al., 2008; Parmar et al., 2010; Eden and Ackermann, 2013).

Instead, this study visits some of the applications of stakeholder concept in research areas that are related to the application of new urban air pollution monitoring instruments. Such fields include the business management where the concept was originally developed and has been explicitly used, policy-making and governance, natural and environmental studies (e.g., natural resource management, sustainability and environmental management), and technology development. This review attempts to identify the key attributes that distinguish the term from other cases than the one of study. Thus, a useful method to define end-user stakeholders in an air-pollution monitoring context can be developed.

2.2.2 Stakeholders in business/corporate studies

For a long time, scholars debated who may be considered as a stakeholder, and what the stake is, as the definition of stakeholder largely depends upon the interpretation of *stake* (Freeman, 1994). Many of the discussions can be found in the field of strategic management. In the mid-1970s, the system theorist Russell L. Ackoff (1974) noticed the importance of involving stakeholders in the planning process of corporate policy-making and argued that the redesign of fundamental institutions in a system (organisation) with the support of stakeholders can solve many societal problems (Freeman and Reed, 1983, Eden and Ackermann, 2013). Dill (1975) describes stakeholders as a broad aggregation of people outside the firm '*who have ideas about what the economic and social performance of the enterprise should include*'. He noticed the concern of social impacts of business and incorporated *stakeholder participation* instead of *influence* into the discussion of corporate strategic management. In Freeman's classic definition the *stake* is undefined, the description of '*can affect or is affected by*' leads to a broad and open stakeholder group. Yet the intention of the concept is fairly clear. Management should recognise the importance of groups beyond their shareholders, and also the success of an organisation depends upon how it manages relationships with those who can affect the realisation of its objectives (Mitchell et al., 1997; Freeman and Phillips, 2002).

Clarkson's (1995) narrow definition was built on the topic of the moral responsibilities of business, i.e., corporate social performance (CSP), corporate social responsibility (CSR) or corporate social responsiveness (CSR). The definition describes stakeholders as '*persons or groups that have, or claim, ownership, rights, or interests in a corporation and its activities, past, present, or future*'. Clarkson further classified the stakeholder into primary and secondary stakeholder groups (ibid.). Primary stakeholders are vital for the corporation, while a lower level of interdependence exists between the firm and the secondary stakeholder group. The analysis takes its root in strategic management but shifts the focus from the management of stakeholder relationships to the social performance of business. Drawing on Clarkson's work, Hillman and Keim (2001) adopted the primary stakeholder definition and used it to analyse the relationship between economic performance and social performance. Their results indicate that a good relationship with primary stakeholders, including shareholders, employees, suppliers, customers, and communities where businesses operate, might positively affect the firm's financial performance and therefore shareholder dividends (Hillman and Keim, 2001).

There is also discussion of the term stakeholder in the field of finance. In an early piece, Cornell and Shapiro (1987) suggested that the non-investor stakeholders play an important role in corporate financial policy. Instead of using the term stakeholder explicitly, the researchers followed the idea of considering the firm as a set of interrelated contacts among various claimants that *'go beyond stockholders and bondholders to include customers, suppliers, providers of complementary services and products, distributors, and employees'*, as *'a contractual coalition that includes both investor and non-investor stakeholders' (ibid.)*. The authors then carefully examined the distinction between explicit claims and implicit claims. Stakeholders have an important role to play if both explicit contracts, i.e., legally binding contracts, and implicit claims are considered. Though the implicit promise, such as the work environment, promotion opportunities, and benefits for long-term relationships, such as for loyal employees and contractors, has little legal standing, it may largely affect the turnover and marketing performance of the firm (ibid.). Following the work of Cornell and Shapiro (1987), other studies have been carried out to analyse the impacts of stakeholder involvement in business. The central topic is the relationship between stakeholder management and financial performance. For instance, there are studies by Bowen et al. (1995), Holder et al. (1998), and Zingales (2000).

The stakeholder concept originates from business and corporate studies and derives from the attentions on shareholders and their influence on the firm's well-being. Stakeholder theory also is a significant approach that opens up the discussions on how to distinguish and manage the relations and what possible outcomes different relationships would bring in. Analysts recognise that companies are located in a network and a variety of actors can affect the success of the firm. In a simpler and slightly naive way this is to say that doing business is all about identifying and managing relationships between the units that are in the network, or those are just visible enough to be identified, and the firm. That simplified idea can be extended to a range of fields. For this research, if air-quality monitoring and management is regarded as a business, atmospheric measurements can be used for management. Then monitoring technologies are the tools that the organisation employed in order to deliver the product – air quality measurements, which is used both internally, for example to make air-quality management plans, and externally by the purchasers, i.e., users of processed data. The external use then provides feedback for the operators of the business to adapt the tools if necessary and if feasible. Hence a range of actors, including end-users, and their relations can be sketched in the network of urban air-quality monitoring and management. Yet unlike other products whose performance can be evaluated by assessing the market share, pollution data and its producers are strongly affected by political and social economic factors. The relations and interests, as well as associated conflicts are also multi-dimensional. Based on the literature, a sketch of the relations between monitoring practice operators, monitoring technology, pollution monitoring data and its users in border context is illustrated in the following figure.

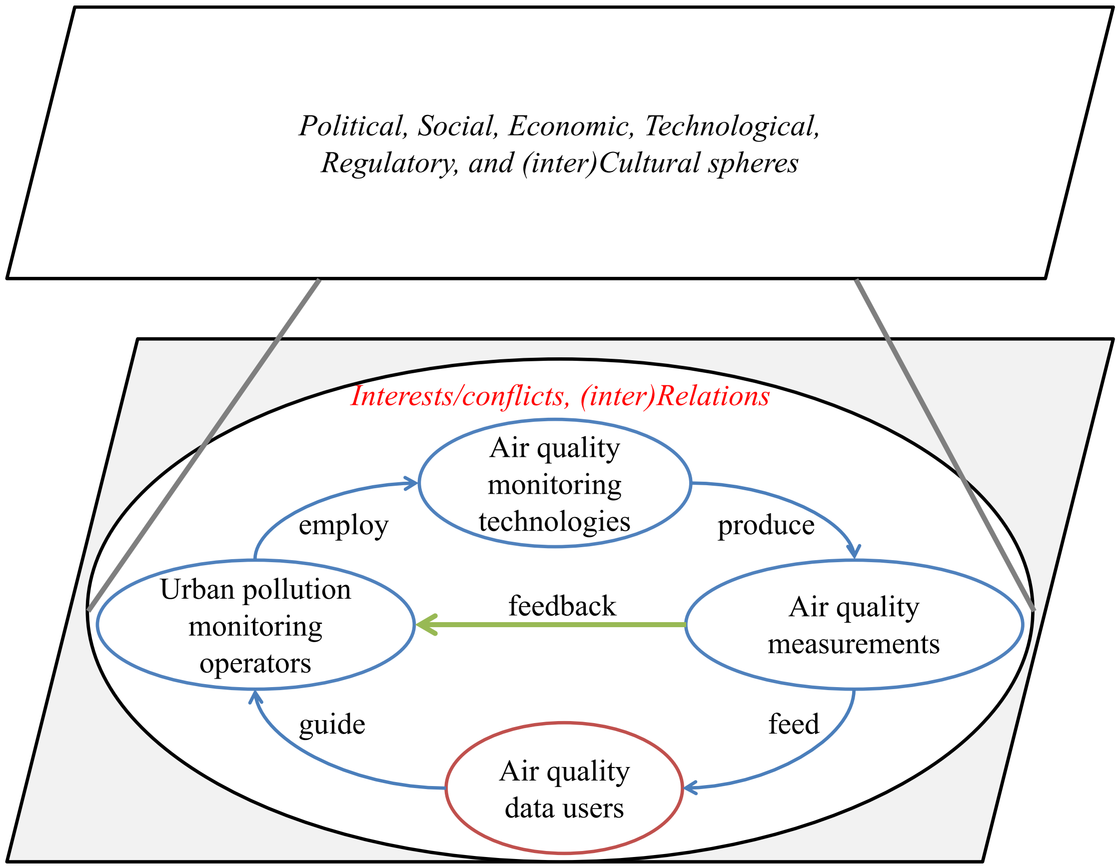

Figure 2- 1 Sketch of urban air-quality monitoring-network and the relations

2.2.3 Stakeholders in policy-making and public administration

Governance theorists and practitioners in public affairs, such as policy makers, public managers and officials in public sector at all levels have noticed the influence of various societal actors over policy-making, especially in western democracies, and have made connections with stakeholder thinking (Freeman and Reed, 1983; Peters and Pierre, 1998; Lynn et al., 2000). In public management the approach can be employed in participatory public policy-making process (Edelenbos, 1999; Edelenbos and Klijn, 2006). This approach is process-oriented. It considers policy-making as a process that involves various actors who may interact with each other and create shared policy content, assuming that many actors in society are affected by policy decisions and they will all have their own perspectives on problems and solutions (Edelenbos, 1999). Edelenbos and Klijn (2006) evaluated the involvement of different public actors in the policy-making process in the Netherlands and discussed stakeholder participation in the interactive decision-making process, i.e., participatory decision making. In the analysis, the stakeholders are groups of societal actors who *'not only possess vital resources to realise policy goals and outcomes but also have different perceptions on the problem definition and have different information and ideas on solutions'* (p. 419), followed by describing the conflicting interests of stakeholders may impede decision making, and state the '*stakeholders include societal organisations, private parties, and organized and nonorganized citizens'* (Edelenbos and Klijn, 2006). In the study, social actors and the stakeholders are interchangeable terms, but exclude policy makers and public managers. The researchers conclude that the outcomes illustrate that there is no correlation between the involvement of a wider variety of stakeholders and positive outcomes. In other words, without good process management the involvement of stakeholders can result in a negative outcome and fail to achieve the objective of participatory decision-making, forming consensus about the content of the policy between different actors.

From the above it is clear that noticing the role and relationships of different stakeholders is an initial step, but that it is necessary to have a strategy to manage the involvement of stakeholders. Otherwise policy decisions may not reflect the preferences of those stakeholders. This observation is consistent with insights from strategic management, that a classification system to identify different stakeholders is important, but a method to cope with conflicts is equally important (Ackoff, 1974; Clarkson, 1995; Jensen, 2001). In addition, the objective and scope of stakeholder involvement should be clear, and the temporal character should be noticed. An agreement made between actors can be a result of a trade-off across different interests that are contextually and temporally specific and therefore may not bring positive impacts in long term (Grimble and Wellard, 1997; Brugha and Varvasovszky, 2000; Jensen, 2001).

2.2.4 Stakeholders in natural and environmental studies

The stakeholder concept has received attention in natural and environmental studies as well, largely as a response to the emerging environmental agenda in the 1990s, e.g., Agenda 21 (United Nations

Conference on Environment & Development, 1992). Stakeholder analysis became a popular tool for identifying the actors and their respective influences on natural and environmental issues (Altman and Petkus Jr, 1994; Grimble and Wellard, 1997; Grimble, 1998; Reed, 1999; Brugha and Varvasovszky, 2000; Reed, 2008; Reed et al., 2009; Prell et al., 2009). In the field of natural resource management, resource management, or environmental resource management, the term stakeholder is interpreted as individuals or groups of actors who have a common interest in a particular environmental issue, and by identifying the key stakeholders and their respective interests, stakeholder analysis is able to resolve the conflicts, as well as the impact of any changes to the system (Grimble and Wellard, 1997; Grimble, 1998). Here the stakeholders include a wide range of society, from natural resource users, development practitioners, governmental bodies or international agencies, to industries and non-governmental organisations (NGOs) (Grimble, 1998). Depending on their form of involvement, the stakeholders can be divided into those who affect (*active*) or are affected by (*passive*) a decision or action (Grimble and Wellard, 1997). Also departing from the resource aspect, stakeholders can be as *'individuals, groups, and formal organisations who have a perceived interest or impact on a particular resource'* (Selin and Chevez, 1995). Similarly, Prell et al. (2009) refer to the broader definition of stakeholder from Freeman, meaning *'individuals who affect or are affected by certain decisions and actions'* (p. 515). The analysts argue that stakeholders can be categorised depending on their perceptions of an issue, and/or their respective influence on the issue (Prell et al., 2009). These notions have a wider range that cut cross society as a whole.

In the field of environmental policy development, Altman and Petkus (1994) devised a conceptual framework through which the policy-making process can be analysed from a social marketing perspective, from which the legislative body plays a role as the '*organisation*', and stakeholders are the '*customers*' who have an interest in or need the product - environmental policy. This definition separates governmental policy makers and stakeholders, i.e., non-governmental stakeholders, into two groups. While trying to analyse the participatory process in making environmental decisions, Reed (2008) focused on the methods and approaches for stakeholder participation. In the study the broader view of the stakeholder concept is applied, where it is seen to refer to *'those who are affected by or can affect* *a decision'*, *'who hold a stake (whether directly or indirectly) in the scope of their initiative'*, or *'individuals and groups who are affected by or can affect those parts of the system (this may include non-human and non-living entities and future generations)'*. The analysis considered participation as a process, in which relevant stakeholders are identified and/or categorised by applying stakeholder analysis (ibid.). In addition, researchers have attempted to connect the stakeholder concept to sustainability issues, yet the theory is still under discussion and no clear conclusions have been drawn (see Bäckstrand, 2006; Garvare and Johansson, 2010; Starik and Kanashiro, 2013; Hörisch et al., 2014).

This is to say when taking the effects on nature and environment as an objective, extra complexity is added to the classification approach. The perceptions and influence of stakeholders on both social economic behaviour and environmental actions can be used to classify the types of stakeholders. For this research the deployment of new air-quality monitoring technologies is driven by environmental policy decisions, which affect the natural environment, but it also consists of technological-development processes (Figure 2-1). It is, therefore, necessary to understand how end-user stakeholders are involved in science and technology development.

2.2.5 Stakeholders in science and technology development

Given the dynamic nature of science and technological development, which embraces various expertise and values, the importance of the stakeholder approach has been recognised. Tipping et al. (1995) emphasised that different stakeholders have different interests in R&D, and it is important to ensure their involvement over time. Previous research also found that along with the progress of an R&D project, the interest of stakeholders and their salience from the view of the project manager would change, as well as their power, legitimacy and urgency (Elias et al., 2002; Mitchell et al., 1997). Hall and Martin (2005) analysed the role of stakeholders in the development of radical technologies, which are often controversial and accompanied by public concerns, e.g., the application of genetic technology in food and feed. The researchers pointed out that the development of radical technologies may involve more social, economic, environmental and regulatory uncertainties that add extra challenges to the process (ibid.). In addition, depending upon the role and proposition (for example, research sponsors, industry promoters, researches, different groups of activists), the stakeholders may have intensely different objectives, and some stakeholders, often those who are outside the innovation value chain, therefore may play a disruptive role in technology development (Hall and Martin, 2005). Hence, understanding the relationships between stakeholders and technology developers is an essential means by which the unintended consequences of the technology development can be managed or minimised.

From its origin in business studies to the employment in many other disciplines, the stakeholder concept has been used and perceived in heterogeneous ways. This diversity is a result of changing objectives, contexts, and interests/conflicts of actors at all levels. Therefore, it results in different methods for addressing and evaluating stakeholders' involvement and relations. This research involves technology development and environmental policy-making, and its objective is to understand the factors that affect successful uptake of non-regulatory air-quality monitoring technologies in cities and the user's needs. It is related to an activity, urban pollution monitoring and relates to air quality management aiming to reduce air pollution. The stakeholders thus are those who have a stake in pollution monitoring and management and is interested in using these technologies. The end-user stakeholders' involvement is further discussed in the next section.

2.2.6 Identified gaps in the current stakeholder literature

The stakeholder concept has extended from business-management studies to various disciplines, and there are attempts to include the natural environment as a stakeholder to broaden the stakeholder network. Yet, the discourse for exploring wider technology-society-environment relations remains underdeveloped in three key ways.

First, the majority of the stakeholder literature comes from the business studies, which has meant that political, social, regulatory and (inter)cultural factors are not well integrated into the analysis, which require more investigation. This study employs the stakeholder approach for analysing technology-environment-society-policy relations, specifically in the setting of urban air-quality monitoring in different governance regimes. Additionally, the transboundary character of air pollution, draws the attention on local-regional-national-global effect regarding the issue.

Second, stakeholder theory employs system-thinking which requires a system boundary. The involvement of urban environment may result in a blurred edge, as it is difficult to apply the extant classification systems of stakeholder framework to analyse relationships. Exploring a way to identify key end-user stakeholders and their respective relation with air quality management is, therefore, a key objective of this project.

Third, though the dynamic nature of stakeholder relations is reflected by their characteristics, i.e., changing roles and interests, more contextual factors should be considered when analysing air quality issues, for example the geographic conditions and international relationships. The context helps to understand what may drive the change and what result would take place. This study takes into account the temporal and geographic considerations and attempts to provide an interpretation in sense of the dynamics in stakeholder network. However, it should be clear that this research focuses on end-user stakeholders only. Stakeholder is a wider concept and some of the stakeholder types are outside the interest of this project, for instance the business stakeholders of the technology companies, the material providers and manufactures of the device. The end-user stakeholder is used interchangeably with end-user hereinafter.

2.3 Developing an end-user stakeholder network

A stakeholder approach offers a method for the identification of actors and their respective relations and interrelations as it relates to a complicated topic or wicked problem, that is associated with networked relationships and coupling effects. Urban air quality management is a classic example of such a wicked problem. As a tool used in air quality management, the deployed monitoring instrument should be cost-effective and robust, while the data need to be accurate, reliable and sufficient (WHO, 1999; Lewis et al., 2016; WHO, 2016; Castell et al., 2017). The generated information may lead to wide-ranging affects that include but are not limited to environmental policy, public opinion, social behaviour, industrial performance, and business decisions. Given the widespread implications and relationships that are involved in the subject, a wider recognition of stakeholders (both primary and secondary stakeholders) and analysis of many interacting factors would require extensive resources to identify and analyse.

This study intends to examine the involvement of end-users in the application of emerging low-cost portable air quality monitors in city environments. To explain the proposition of end-users in the business management context, the monitoring technologies and output data can be described as a '*product*' of the technical innovation, the end-users are then the '*customers*', who are '*purchasing*' (using) the products and have an essential role to play when evaluating the '*marketing performance*' (technology uptake and impacts on air quality management) of the product. In that sense, end-users can be classified as *primary stakeholder* in stakeholder approach (Clarkson, 1995). It is beyond the scope of this study to perform a complete stakeholder analysis, it is important to realise that stakeholder approach is applied in order to facilitate identification of end-users in the field (see next section), and what their respective interests are in the deployment of emerging sensing technologies.

By conducting the mapping exercise to identify legislative requirements for air-quality monitoring and management in the three cities at the outset of the study, a range of actors involved in urban air quality issues were recognised. They include but not limited to different levels of governments, emitters, research institutes, and other social groups such as environmental non-government organisations (ENGOs) and citizens. These actors are all stakeholders involved in air quality policy-making. For the development and utilisation of new monitoring technologies, technology providers and manufactures should also be part of the network. As such, the stakeholder network of air-quality monitoring considers political-social-economic-technological-regulatory-(inter)cultural spheres. This scope of the issue results in a group of governmental bodies and societal organisations in the network.

Based on the above, a preliminary stakeholder map of urban air-quality monitoring is developed. The network includes six major groups of actors. They are the *emitters* who are well recognised contributors to urban pollution or industries that require emission control, *global society* which addresses pollution problems at the international level, *national society* that respond to local pollution problems and works closely with international society, *innovation groups* who develop technologies and *business stakeholders* who commercialise the new products, as well as *social groups* which cover a wider audience concerned about air pollution and its impacts.

The preliminary map is presented in Figure 2-2, the actors in the network and their relations are discussed in the following section.

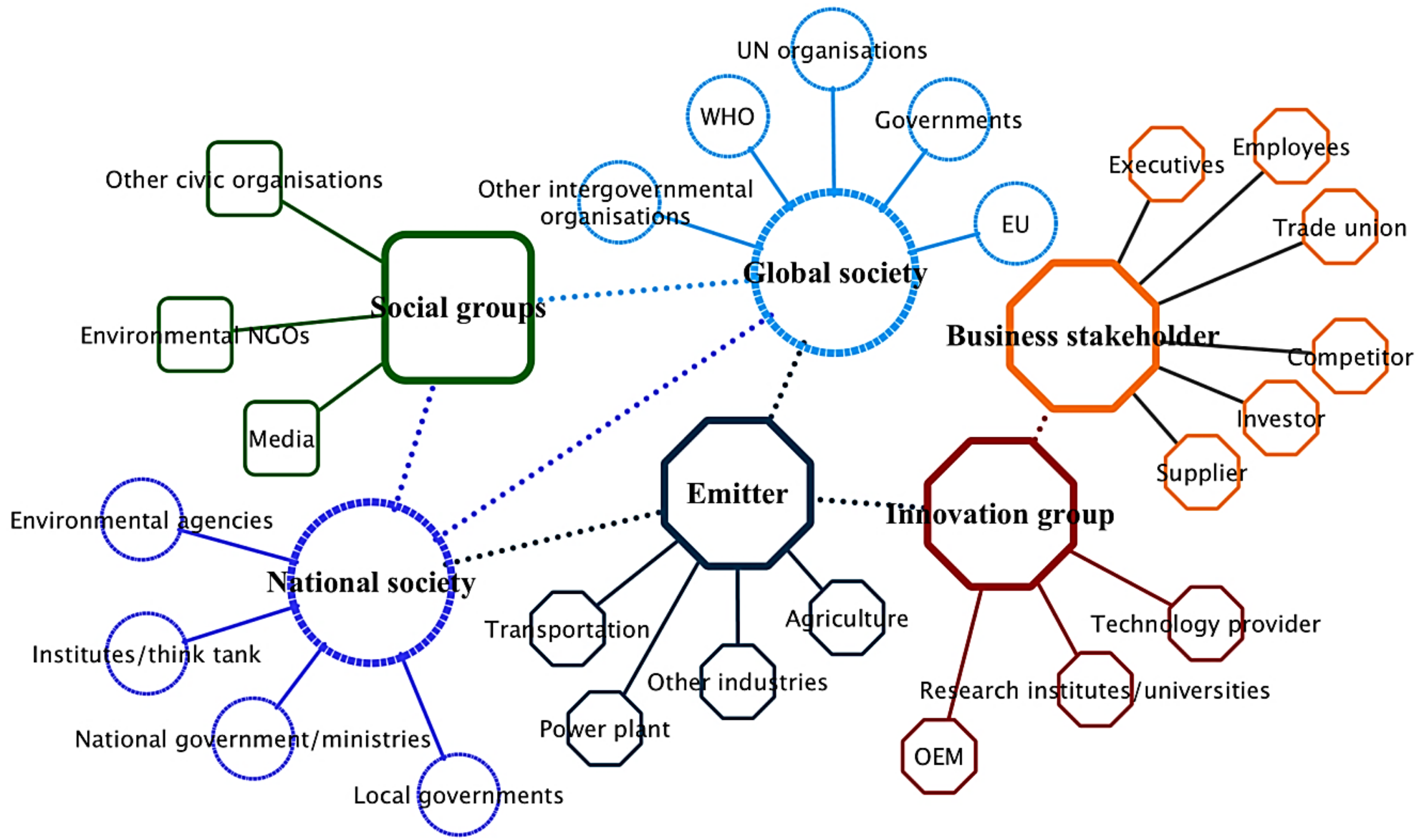

Figure 2- 2 Sketch of stakeholder map of air-quality monitoring in cities

Emitters are the sources of atmospheric pollutants, that release chemicals, which are categorised as pollutants into the environment and require emission monitoring. They are scattered over diverse sectors and can include transportation, power plants, energy-intensive industries such as steel, cement, and petrochemicals, as well as waste incineration plant, and agriculture. The industrial activities not only contribute to the emissions but also the urban economic growth and well-being. Yet industries are resource dependent, and their presence varies geographically. For example, raw material for production and labour force, location, as the products should be able to be easily transported to another place, as well as other social economic status of the city. In order to implement environmental legislation, industries are required to monitor their emissions onment and provide data to the respective authorities. In this case, the emitters can be the direct-users of monitoring technologies. Yet pollution is a transboundary problem. Although this study investigates air quality in cities, local air pollution can come from another region or even another country, which means that there are links across regional, national and international levels.

Global society includes intergovernmental organisations that coordinate, promote and supervise international cooperation with respect to pollution management between countries, as well as foreign governments who may put political pressure on the home country about air quality issues. This can be done through negotiated agreements, result in regulatory agreement, e.g. the Geneva Convention on Long-Range Transboundary Air Pollution (1979). These agreements are then transposed into national policy systems. The initiatives taken at the global level can also be reflected by non-regulatory actions such as the Intergovernmental Panel on Climate Change (IPCC) reports. Social groups that operate at international level, for instance, World Wide Fund for Nature (WWF), Friends of the Earth make up another part of the global society.

Society at the national level may include the authorities, agencies and contractors that facilitate the government to perform tasks, national academia and think tank that inject scientific inputs into the decision-making process and voluntary activities, as well as social groups working on environmental issues. The national authorities most likely act as the information hub for all environmental data. To do so, the executive authorities, such as Ministry of Environment, or agencies operate monitoring stations to collect data or employ contractors to do so. On this basis, the national government is able to release legislation or policies, make performance targets or limitations domestically and participate in international negotiations.

National and international societies work closely. Air pollution is an international issue due to its transboundary nature. It requires international cooperation to set targets and clarify responsibilities for reducing air pollution level. As a result of discussions or agreements made at international level, the global society may drive the actions in the national society.

Another cluster presented in the preliminary stakeholder map regarding air-quality monitoring and management is the innovation group. This group is particularly important in the sense that it provides up-to-date equipment for measuring and sharing air quality information. Research institutes in the group deliver the scientific evidence about the necessity of applying improved urban pollution monitoring measures, presenting technological possibilities, boosting scientific discussion and research on environmental risks and the effects on human well-being. Technology developers and the original equipment manufacturers (OEM) bridge science and technology, and transfer innovation into a commercial product.

Still, commercialisation would not be realised without the involvement of business stakeholders. Business stakeholders can be private investors or banks that provides financial support if needed, the material or service supplier that enable the operation of the technology innovator or the competitors who push the improvement and specify the market of the product. This group includes internal business stakeholders as well, for instance, the trade union, the employee and the executives of the firm (Clarkson, 1995).

Another perspective to illustrate the role of business stakeholders is normative, from the aspect of corporate social responsibility. The environmental performance of an organisation affects and is affected by, economic indices and social image of the business. When there is an environmental incident happened within a factory, the public image of the industry can be negatively affected. One example showing that is what happened in the recent 'Keep it in the Ground' divestment international campaign launched by the Guardian in March 2015 officially, which has called on international funds, universities, unions and other groups to move their investment from fossil fuel industries to act on climate change (Rusbridger, 2015). One of the results of the international movement is that the world's richest sovereign wealth fund Norway's Government Pension Fund Global (GPFG) had removed the investment in 114 companies as a response to environmental issues and climate change, including tar sands producers, cement makers and gold miners, due to their high carbon emissions, deforestation and mountain-top removal (Carrington, 2015). Another example is the BP Deepwater Horizon oil spill, research has indicated that damaged public image is hard to restore and would affect the business negatively (Harlow et al., 2011; Safford et al., 2012). Therefore, good environmental performance can be important to both internal and external business stakeholders. Pollution monitoring provides evidence on such performance.

The other component of the picture is made up of social groups covering environmental NGOs, civic organisations and the media. Here social groups sit apart from the political and scientific area and act as critical friends to the authorities and institutes. The last-mentioned actors often have a higher level of influence on regulating the performance of industry and supporting wider scope of collaboration that could benefit the environment.

The structure presented in Figure 2- 2 is an initial attempt to illustrate the major stakeholders that are relevant to air pollution monitoring in urban environments and the relational nature of end-users. Due to the complexity of the issue and country dependent situations, there will inevitably be information missing. It should also be noted that the relations within the groups are not unidirectional, and the clusters could affect each other. Nevertheless, the overarching element in the topic of air-quality monitoring in city environments is air quality measurements and the users of data, who are part of the network and are important to the implementation of the new sensors in practice. The end-users are customers who purchase the monitors to meet certain demands. They are, therefore, primary stakeholders as discussed previously (Clarkson, 1995).

Yet, there is difference among the customers or end-users in this research. Industrial emitters can implement new techniques to monitor their emissions, and regulators could also employ them in authorised monitoring stations. These groups are direct users of pollution monitoring technologies.

Nonetheless, the focus of this project is ambient air-quality monitoring instead of emission monitoring. Moreover, air-quality monitoring nowadays is largely driven by environmental institutions. The main function of generated air quality measurements is to inform or lobby policy makers towards ambient air quality improvement. If such purpose is added into the technological-development value-chain, the users of data and processed information presumably play a more important role than direct technology users. And among the users, policy makers are arguably the central group. Yet, this is not a one-way street: the interpretation and perception of air quality data would guide the next generation of technology development, as well as the 'hot spot' in scientific research and public policy-making.

To extract end-user stakeholders from the general stakeholder map, a flowchart is developed to present the location of different business stakeholders and end-user groups mentioned in the above. End-user groups locate at the last three blocks of the chart, mainly including direct end-users of the technology and end-users of air quality knowledge. Specifically, direct end-users of technology operate and maintain monitoring devices. They also receive raw measurements but may not further use the data. Other end-user groups are direct users of generated knowledge, including end-users of raw data and simplified information. The first group receives raw air quality measurements and interpret the data according to their respective needs. For instance, atmospheric scientists may select relevant datasets for dispersion modelling, civil servants need to standardise these data to compare with regulations and inform the public and policy makers. Last, at the end of the chain are the ultimate users of information who receive the processed air quality measurements. This group may include policy makers, policy analysts, interested groups as well as the general public. The diagram is based on the stakeholder literature and end-user studies, as well as product development research (Cooper, 1983; Srivastava et al., 1999; Schot and Geels, 2008; Keskin et al., 2009). Their relationship is presented in the following Figure 2- 3.

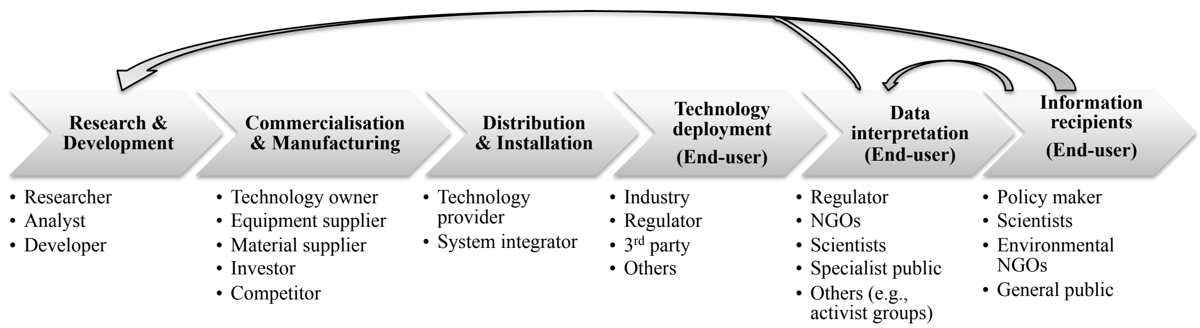

Figure 2- 3 Stakeholders in the simplified technological development value chain and position of end-users of monitoring data.

With respect to the relations between end-user stakeholders and other stakeholders, research and development (R&D) block is part of the innovation group in the stakeholder network. R&D is the phase in which researchers, analysts and developers together make new technology a realistic product. After lab work and pilot test and/or demonstration in the R&D phase, the technology scales up and becomes commercially available in the commercialisation and manufacturing stage. After distribution and installation, the product, therefore, is ready to be used by end-users of the device and generate output. The actors involved in commercialisation and manufacturing, distribution and installation phases are mainly business stakeholders. A mixture of emitter, national society and potentially social society present in the technology deployment stage. Following that, data interpretation is mainly formed by the societies at national and international levels. The technology deployment is the last stage of the product development chain, where several user groups of the device present. Yet there may be overlaps between end-user of technology and end-user of data and recipients of information. For example, the civil servants could be both. Furthermore, direct technology users are able to affect the product design by giving feedbacks or complaints, as discussed in section 2.3.5, so are also data interpreters. Nonetheless, the indirect users of technology, i.e., direct end-users of data and information, can be more active at a broader spectrum, lying in the general political-social-economic-technological-regulatory-(inter)cultural sphere, therefore, are the focused groups for this study.

Based on the above, though there are diverse applications and views on what *'end-user'* means, it is possible to develop a working definition of the term drawing upon various literature that can be applied in this research:

- End-users of air-quality monitoring in city environments are people and/or organisations who eventually receive and utilise the data in activities that could guide, steer or affect social behaviours and/or actions towards cleaner air in the society. These behaviour changes and/or actions can affect urban air quality and human well-being as a whole. They are interested in environmental issues and may have certain level of power and/or influence over the development and deployment of pollution-monitoring techniques.

Urban air quality data here refers to the contamination information directly and/or indirectly generated by various monitoring devices that indicate the extent or levels of ambient air pollution in cities. Such data include most concerned atmospheric pollutants which have adverse effects on the environment and human well-being, such as concentrations of PM 2.5 in the air. The following data is part of the environment datasets but not considered as pollution data in this study:

a. Environmental measurements other than ambient air, such as indoor air, industrial emission, water quality, soil and urban noise measurements.

b. Environmental indicators provide the background information that is needed in generating the pollution map. For air pollution that can include temperature, humidity, and meteorological data.

c. The geographic information used for identifying the pollution source or predicating changes.

d. The other environmental datasets such as biodiversity, agricultural environmental performance, and climate change potential, etc.

This research focuses on ambient air-quality monitoring and management in cities. The socio-economic and political information are not considered as environmental data but are used as to support the contextual analysis.

Typical end-users of monitoring data include policy makers and civil servants at different governance levels, environmental NGOs, the specialist public (e.g., communities and individual environmental activist), media, and other social groups (e.g., charities, institutes, environmental consultancies, and civic organisations).

Given the fact that environmental actions are largely affected by political willingness and opinions on environmental issues, it has to be rooted in existing governance structures. This will be discussed in the following analytical chapters, within which the governance regimes in each of the study cities and experiences of implementing air quality policies are explored.

2.4 Conclusion

This chapter has reviewed the definition of end-user and the applications of stakeholder theory in order to define the meaning of end-user in terms of urban air-quality monitoring. The context and theoretical arguments underpinning the concepts were reviewed. The study of end-user literature indicates that while focusing on differentiating users of a specific technology and others involved in the development, the concept of end-user is not able to capture the relationships between different user groups. The term also fails to provide a guideline to analyse their involvement. To address these limitations, the researcher turned to the stakeholder literature in order to find ways to extend and better understand the relations between affected actors in air-quality monitoring business. I developed a working definition of the end-user stakeholder by reviewing the two sets of literature. The term end-user stakeholder refers to a subset of stakeholders in the context of urban air-quality monitoring. This definition enabled the researcher to identify potential participants of research interviewees so as to explore their perceptions of new air-quality monitoring practice.

Chapter Three Methodology and data

3.0 Introduction

This chapter outlines the methodology used to establish the needs of different end-users of new air-quality monitoring technologies in cities. The study applies the stakeholder concept as a bridge to identify and explore the role of end-user stakeholders with respect to urban air-quality monitoring. The research also employs grounded theory in order to develop a theoretical framework for establishing the needs of end-users. This chapter presents both theoretical underpinnings of the research and associated analytical process and methods.

Firstly, section 3.1 and 3.2 identify qualitative research as an appropriate methodology and grounded theory as the approach to explore the involvement of end-user stakeholders in urban air quality issues. The adoption of new air-quality monitoring technologies in cities evolved as a multi-disciplinary topic that involves environmental science, environmental policy, social science, and technology innovation at least. Though this research draws from an end-user perspective and utilises the stakeholder concept as a guideline for identifying end-user stakeholders and their respective interests, there is no theory that could be applied directly to attain and analyse user needs or the scope for using new air-quality monitoring devices. The theoretical approach for establishing end-user needs is grounded within each specific setting. In order to better understand the context of air quality monitoring in a specific urban area, the relationship between potential end-users and their respective needs, this research draws upon early studies in the fields of environmental politics, environmental risk perception, and technological innovation, as well as epidemiological evidence, public attitudes and behaviour surveys. Yet, it should be noted that an inductive approach is used that tries to understand and explore the needs of end-users in the three cities but does not aim to test any hypotheses or predetermined assumptions.

The following section 3.3 and 3.4 present the methods of data collection and data analysis. Semi-structured expert interviews were selected as the means to obtain empirical data. The complexity of air quality requires professional and representative opinions, while the relational nature of stakeholders highlights the importance of being aware of the relationships and interests among the end-users. The participants were invited to share their opinions of air pollution monitoring and emerging new technologies, perceived impacts of the data, as well as their views on future pollution-monitoring practice through face-to-face conversations. By carrying out the semi-structured interviews, key issues and concerns associated with air-quality monitoring and pollution data were able to emerge. Together with other data sources, such as government documents, policy papers, and reports, the interview content provided the basis for analysing the collected information. Section 3.5 addresses the ethical aspects of this research.

3.1 Qualitative research

Qualitative study delivers research outcomes through analysing non-statistical data. Qualitative research is a useful umbrella term that covers a wide variety of research methods which aim to understand the underlying perspectives referring to the issue under study and supports the development of new concepts or hypotheses if needed, and is widely applied in social research (Strauss and Corbin, 1990; Flick, 2008; Bryman, 2012). The identified aim of this project, establishing the needs of end-users with respect to urban air-quality monitoring, and the respective research questions, support a qualitative research enquiry. By collecting and analysing rich qualitative data, this study explored various underlying issues that affect end-users' opinions on adopting new monitoring technologies, such as the function of air quality information, the impacts of environmental governance regime on pollution monitoring activities, and other social factors. The overall narrative was organised by integrating the findings of each case study.

Qualitative research offers number of advantages. First, it provides the opportunity for researchers to get in-depth information about social phenomena that often are not readily susceptible to quantitative evaluation, such as feelings, emotions or process of conceptualisation (Strauss and Corbin, 1990; Ambert et al., 1995). Second, the overall aim of qualitative research is to gain insights into the topic of interest in a limited number of cases. As such, large amounts of numeric data that could represent an entire area of study to produce accurate evidence is not required (Glaser and Strauss, 1967; Patton, 2014). In addition, qualitative studies provide the basis for further quantitative research if needed, or initiates new ideas and/or research areas, as the methods encourage people to expand their responses (Britten, 1995; Bryman, 2006) and these expanded responses can lead to new lines of enquiry.

Numerous approaches to doing qualitative research are documented in the literature. Different researchers have different perceptions on the meaning of qualitative research, which not surprisingly has led to the development of diverse strategies and procedures for carrying out qualitative research across different disciplines (Flick, 2009; Wertz et al., 2011). Creswell (1998) outlines five general traditions of qualitative inquiry: narratives (or biography), phenomenology, grounded theory, ethnography and case study. Wertz et al. (2011) presents another five ways of doing qualitative analysis, namely phenomenological psychology, grounded theory, discourse analysis, narrative research, and intuitive inquiry. Patton (2002, 2014) identifies sixteen theoretical inquiries based on the research questions that need to be addressed: ethnography, autoethnography, reality-testing and foundationalism, grounded theory, realism, phenomenology, heuristics, social constructivism, narratology, ethnomethodology, symbolic interactionism, semiotic, hermeneutic, systems theory, complexity theory, and pragmatism and generic qualitative inquiry. Tesch (1990) distinguishes twenty-six different types of qualitative research according to the interests of the research (see Figure 3- 1). At the same time, many other analysts focus on specific types of qualitative research (Glaser and Strauss, 1967; Riessman, 1993; Coffey and Atkinson, 1996; Stake, 1995; Atkinson and Hammersley, 1994).

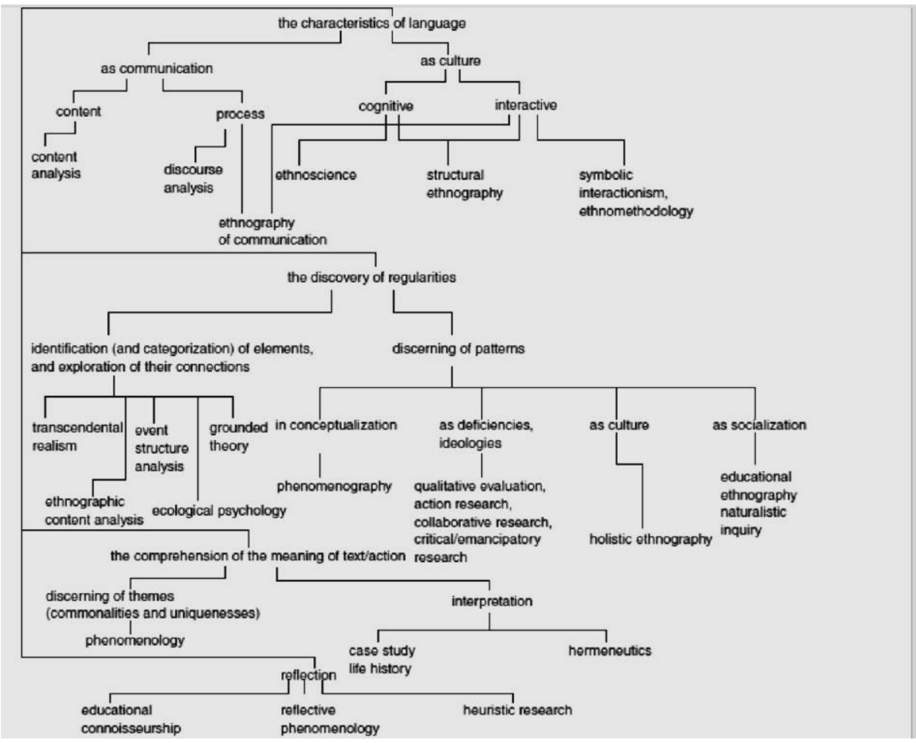

Figure 3- 1 Types of qualitative research based on research interests, by Tesch (1990, p. 72)

Despite the diversity of methods, qualitative research is about the collection, analysis and interpretation of any nonnumeric data. Qualitative data can come from a number of sources such as interviews, documents, pictures, observations, video or audio records (Corbin and Strauss, 1990; Bryman, 2012). The data are often analysed through an inductive strategy and results in richly illustrative findings of the topic under study (Patton, 2014).

Qualitative research is an appropriate approach for this project. Firstly, the research problem of how to establish the needs of end-users leads to a set of qualitative questions. For example: who the end-users are, how they are involved in air quality issues, and what underlines their perception of emerging monitoring practice. The expert opinions and clarity of examples can reveal individual understanding of air quality issues and provide an overview of the status quo regarding local air-quality monitoring and management in each city. In addition, this study attempts to explore the possibility of developing a framework that enables the formation of user needs in relation to new air-quality monitoring practice. Through qualitative inquiry the researcher is able to gain a deeper understanding of the relations between air quality data and the respective users, the dynamic network of end-users, as well as the contextual factors that affect air pollution monitoring practices. In this case, qualitative data such as environmental reports, expert interviews, and visual materials presenting the practice provide more insights than statistical data. It should be noted that due to the inductive nature of this project, and the manner in which it seeks to explore the user needs of air-quality monitoring in three cities, no standardised procedure or technique is followed dogmatically. Complementing Strauss and Corbin (1990) the position is taken that *'analysis is not a structured, static, or rigid process'*, a mixture of methods that fit the project is applied in response to emerging themes in this interdisciplinary and complex topic of research. The following section outlines the methods that were used.

3.2 Grounded theory

Grounded theory (GT) is a *general method of (constant) comparative analysis*[6] in which the explanatory theory develops from data and suits its supposed uses (Glaser and Strauss, 1967). Grounded theory

[6] Glaser and Strauss (1967) use comparative analysis as a strategic method for generating theory that develops from comparisons between social units of any size, ranging from individuals or their roles to nations or regions (p. 21).

approach suggests that concepts and hypotheses can be generated from the empirical data along the research progress systematically. As such, GT provides inductive methods to develop theory through the process of data collection and analysis (Glaser and Strauss, 1967; Morse, 2001; Mills et al., 2008). Though there is an emphasis on qualitative data, it is applicable to both qualitative and quantitative research (Glaser and Strauss, 1967).

The core strategy of the original grounded theory by Glaser and Strauss is to generate theories systematically by applying the logic and rigour methods of quantitative research to qualitative data analysis (Glaser and Strauss, 1967; Walker and Myrick, 2006). Glaser and Strauss (1967) criticised the mainstream of social research in the 1960s because it overemphasised the importance of verification in relation to the generation of theories to explain social structures and social systems. To perform validation work, the majority of social researchers preferred to adopt quantitative methods as they took the view that qualitative data were not as capable as quantitative data to produce accurate evidence to verify the theories, as it was used in a '*non-systematic and non-rigorous way*' (p. 15). They also criticised the traditional quantitative and qualitative methods, especially the popular logico-deductive theory, for being based on *a priori* assumptions and not empirically based. Glaser and Strauss (1967) argued that the generation of theory and validation should receive the same treatment in social research, and both forms of data are useful. The qualitative method is often the best way to generate hypotheses, which provides the basis for quantitative data analysis to test (Glaser and Strauss, 1967). In order to achieve the systematisation of qualitative research for theory development, Glaser and Strauss, therefore, suggested several techniques for data collection and analysis in their book *The Discovery of Grounded Theory* (1967), following their study of dying patients in hospitals, which was published as *Awareness of Dying* in 1965 (Corbin and Strauss, 1990; Kenny and Fourie, 2014).

Yet, over time different versions of grounded theory emerged. The two originators, Glaser and Strauss, have different opinions on the interpretation of the approach which eventually lead to an academic schism in grounded theory (Heath and Cowley, 2004; Van Niekerk and Roode, 2009). The divergence was not widely recognised until Strauss, and in cooperation with Corbin for the latter work, published two books, *Qualitative Analysis for Social Scientists* (Strauss, 1987) and *Basics of Qualitative Research*

(Strauss and Corbin, 1990), in which the procedures of GT methodology are redefined. One of their students, Kathy Charmaz, joined the debate and proposed another version, the constructivist grounded theory (Charmaz, 2008). The three, classic (or Glaserian), Straussian and constructivist grounded theory, became the dominant configurations among grounded theorists (Mills et al., 2008, Charmaz, 2014, Kenny and Fourie, 2014, Stern, 1994). This research does not intend to contribute to the academic debate. Instead it looks at the differences in techniques and procedures, revealing a suitable methodology for this research setting. The philosophical perspectives of the divisions and history of the arguments are detailed elsewhere (Annells, 1996; Melia, 1996; Boychuk Duchscher and Morgan, 2004; Heath and Cowley, 2004; Bryant and Charmaz, 2007; Van Niekerk and Roode, 2009; Kenny and Fourie, 2014). The divisions of grounded theory, particularly the Glaserian and Sraussian models, caused confusion for researchers who want to use the theory but are not familiar with the methodology, as the divergent versions lead to different grounded theory techniques and procedures (Boychuk Duchscher and Morgan, 2004; Heath and Cowley, 2004; McCann and Clark, 2004; Van Niekerk and Roode, 2009). It is, therefore, important to be clear about the differences and specify which methods are being applied in this research.

The major difference between classic and Straussian GT methods concerns how to conduct data collection and analysis. The Glaserian GT is more faithful to the original approach, and remains abstract and conceptualised (Heath and Cowley, 2004). It is '*simply a set of integrated conceptual hypotheses systematically generated to produce an inductive theory about a substantive area*', claimed by Glaser and Holton (2004, p.2). In contrast, Straussian GT evolved in a way of introducing new rules, guidelines and suggested techniques to make methods more clearly formulated and easier to apply (Strauss, 1987; Corbin and Strauss, 1990; Van Niekerk and Roode, 2009). More specifically, Strauss and Corbin proposed three coding techniques, including open, axial, and selective coding, instead of the two in Glaser's approach (open and theoretical coding) (Strauss and Corbin, 1990; Glaser and Holton, 2004).

There is also a difference with respect to the role of literature. In '*The Discovery'*, Glaser and Strauss (1967) had the opinion that literature should be avoided: '*An effective strategy is, at first, literally to ignore the literature of theory and fact on the area under study'* (p.37). Glaser (1998), as in many other aspects, supports the original theory, stating '*do not do a literature review in the substantive area and related areas where the research is to be done*' (p.67) (cited in Dunne, 2011). More recently, Glaser and Holton (2004) state '*the pre-study literature review of QDA is a waste of time and a derailing of relevance for the GT study*' (p.13). The main reason is that through the lens of Glaserian GT, the reading of literature should take place after the analysis or the emergence of new concepts, as pertinent literature may affect the process of discovery new theories and, therefore, should be delayed (Heath and Cowley, 2004, Van Niekerk and Roode, 2009, McCallin, 2003). In contrast, Straussian GT advocates reviewing of the literature. Strauss and Corbin (1990) argue that '*concepts derived from the literature can provide a source for making comparisons to data at the dimensional level*' (p. 49). They recognised that prior knowledge is almost unavoidable as the research needs an introduction to frame the research question. In addition, the literature can be used as secondary source of data to support the development of theory (ibid., p. 48-52).

The third version, constructivist GT, sitting in the interpretive tradition, distinguishes between a constructivist viewpoint and an objectivist grounded theory (Glaserian or Straussian GT). It takes into account the different perceptions of both researchers and participants, suggesting that they co-construct the theory (Charmaz, 2008). Instead of accepting that data reflect the reality and the researcher takes an objective position, constructivism argues that the researchers' interpretation affects the generation of theory, and the application of grounded theory is rather a form of social action but not research practices (Charmaz, 2006, 2008). As such, constructivist GT focuses on *how* the theory emerges but not what emerges. Thus, constructivist GT is significantly different from both Glaserian and Straussian theories (Glaser, 2002; Kenny and Fourie, 2014).

This study adopted Straussian grounded theory. The rationale for this decision is based on the following:

1. The researcher is outside air-quality monitoring practices and largely in a position as an *observer* but not *participant*. It is true that the researcher's view and working ritual would affect the research outcome, especially in social matters. However, the researcher in this project collected research data from a variety of sources. Even though semi-structured interviews were used primarily, the researcher collected the data without influencing interviewee' opinions

when conducting the research interviews. There was clear distance between the researcher and interview participants. Thus, 'objectivist' grounded theory was more appropriate to this study. Among the two types of grounded theory, Straussian GT is more compatible with modern social constructivist thinking compared to the classic GT.

2. The macro conditions such as social, cultural and historical factors contribute to a complex topic being studied. Therefore, more explicit guidelines and techniques suggested in Straussian GT were considered helpful.
3. The reading of existing literature aids understanding of the context and importance of the research topic. Instead of blocking the development of concepts, visiting the literature enhanced the process and sensitivity of the sampling. Literature can be used as a source of data. For my study, the policy documents, current situation of monitoring technologies, and environmental practices recorded by other researchers and organisations were particularly important for formulating research questions and supporting research need.
4. Being part of a bigger project about urban pollution made the influence of colleagues, experts and experience in different disciplines unavoidable. The research findings could not purely emerge itself from the data as classic GT assumes.
5. Compared to the other versions of grounded theory, the Straussian model entitles researchers the freedom to apply different methods to perform the research.

The following sections outline the main processes used to apply the Straussian grounded theory. The process starts with theoretical sampling and data collection, in which stakeholder mapping exercise was used in order to identify relevant research participants. Then the procedure shifts to the methods of data analysis explaining how the research processes are related to the research aim and questions.

3.3 Data collection and analysis

3.3.1 Theoretical sampling

Theoretical sampling is one of the core elements in grounded theory. Glaser and Strauss (1967) originally defined theoretical sampling as *'the process of data collection for generating theory whereby the analyst jointly collects, codes, and analyses his [sic] data and decides what data to collect next and* *where to find them, in order to develop his theory as it emerges'* (p. 45). It is driven by the process of generating a theory that applies to a specific topic but not the representativeness to a broader population, in which statistical sampling is often employed (Corbin and Strauss, 1990). That is in line with the purpose of grounded theory, aiming to build a theoretical interpretation of certain phenomenon but not to produce a grand theory per se.

In order to capture in-depth insights for the theoretical interpretation of relations between end-users and new air quality monitors, this research adopted a case study strategy. Using a case study approach allowed the researcher to gain a deeper understanding of new air quality monitor uses in diverse urban contexts (Bryman, 2012). Since air-quality monitoring-networks are widely established in developed countries (WHO, 2006), this study limited the selection of cities within developed economies in order to explore the use of new monitoring technologies for both traditional and emerging practices. Furthermore, given the extensive systems of environmental governance in Europe, this region was selected as it provides a rich source to investigate air quality issues. This study covered two member-states of the European Union: the UK and Germany. The UK has a long tradition of developing environmental policies and has both been shaped by and affected in turn the development of EU environmental policies since it became a member state of the EU in 1973 (Burns et al., 2016). The UK was also a first mover in developing policies to address local air pollution following the great smog of 1952 in London (Mage et al., 1996). Germany, has a strong environmental reputation and has often been depicted as an environmental 'leader' in the EU (Wurzel et al., 2016). In order to bring in more diverse cultural context, this study selected South Korea as the third country, which has experienced a rapid industrialisation and is the most densely populated economy among the Organisation for Economic Co-operation and Development (OECD) countries (OECD, 2006b).

Based on the city profile, the analysis adopted a stakeholder approach to identify the potential end-user stakeholders for developing items for discussion, i.e., grounded theory concepts, categories, and eventually a theoretical framework referring to the use of air-quality monitoring technologies in an urban environment. The feasibility of conducting fieldwork and the availability of data also affected the selection of case study cities.

3.3.2 Study cities

York, England, UK

Located within Yorkshire and The Humber Region in the North of England, York is a city which has a rich heritage. It is one of the Europe's premier tourist destinations, receiving 6.7 million visitors annually (Visit York, 2015) The unitary authority includes the historic city centre and the rural and semi-rural settlements and covers a total area of 272 km^2, with a total estimated population of about 202,400 based on the latest 2011 census of the Office for National Statistics (ONS) (ONS, 2013, City of York Council, 2015d). Geographically, sitting in the Vale of York, the city has a low-lying flat topography at the confluence of two rivers: the River Ouse and the River Foss. The River Derwent runs east of the city (City of York Council, 2015a, City of York Council, 2013b). The local Council is committed to improving the environment, and delivering a sustainable, low carbon economy (City of York Council, 2013a). A geographic outline of York is presented in Figure 3- 2.

York is the test bed for research projects run by CAPACITIE at the University of York, of which this study is part. Detecting, monitoring, modelling techniques regarding air quality, river water quality and noise, are examined in the bigger project.

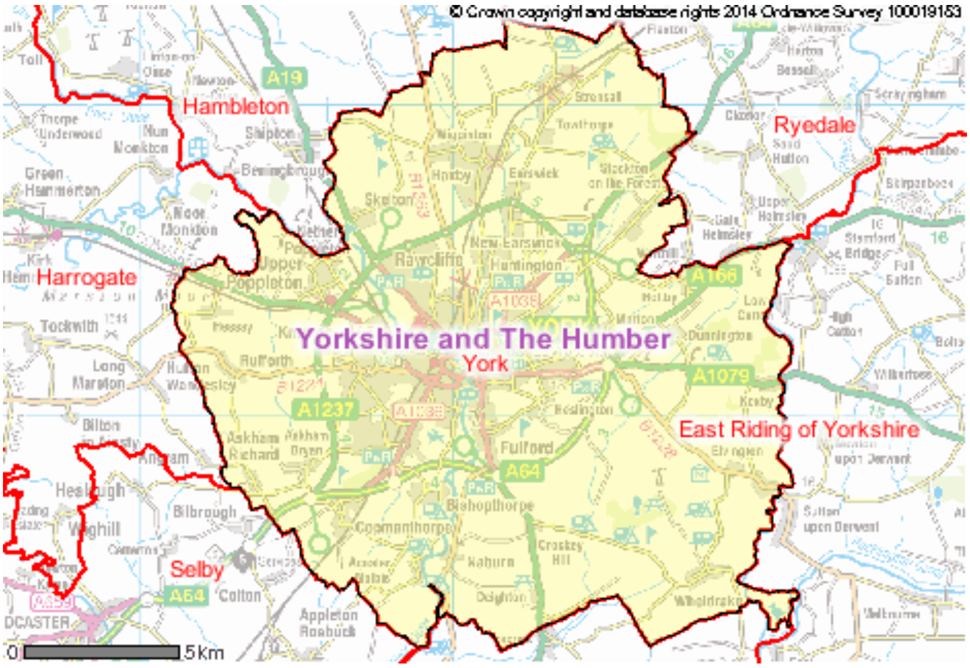

Figure 3- 2 City of York (Source: www.ons.gov.uk)

Berlin, Germany

Berlin, the capital city of the Federal Republic of Germany, with a population of more than 3.4 million, is its largest city. A number of European environmental directives have been transposed to German national law, and Berlin has already achieved some success in environmental management, e.g., the SO_2 concentration has dropped by 90% from 1989 to 2002, and many of the EU Directive 2008/50/EC limit values are being met. For air quality the remaining problems are emissions of Ozone, PM10 and NO_2 (Senate Department for Urban Development and the Environment, 2014). It is, however, believed that one of the main constraints is that these are transboundary pollutants and cannot be solved at city level. The geographic outline of Berlin is provided in Figure 3- 3.

Berlin is regarded as representative of a large European city in this research.

Figure 3- 3 Geographic outline of Berlin (scale 1:50 000) (State of Berlin, 2011)

Seoul, South Korea

With over 10 million people, Seoul, the capital city of South Korea is a megacity. With over 20% of the country's population residing in less than 1% of the total area, the city of Seoul has the highest population density of any city in South Korea (Seoul Metropolitan Government, 2013a). After the Korean War in the 1950s, Seoul experienced the most rapid urban development in the world and made substantial progress towards its ambition of becoming a 'sustainable city'. Yet the city still faces air pollution problems. In 2003, the government launched the Special Act on the Improvement of the Air & Environment for the Seoul Metropolitan Area (the 'Special Act on the Air') to tackle air pollution (enforced in 2005) (Ministry of Environment, 2015c). As a result of these efforts, the pollution level has been continuously decreasing, for example PM 10 concentration was 69 ug/m^3 in 2003 and dropped to 45 ug/m^3 in 2012 (Ministry of Environment, 2015c). Yet further improvements in air quality are still needed.

In addition to local pollution, transboundary air pollutants from neighbouring regions (e.g., China) also contribute to the problem. The study in Seoul helps us to understand the challenges of pollution monitoring in megacities at both local and international levels.

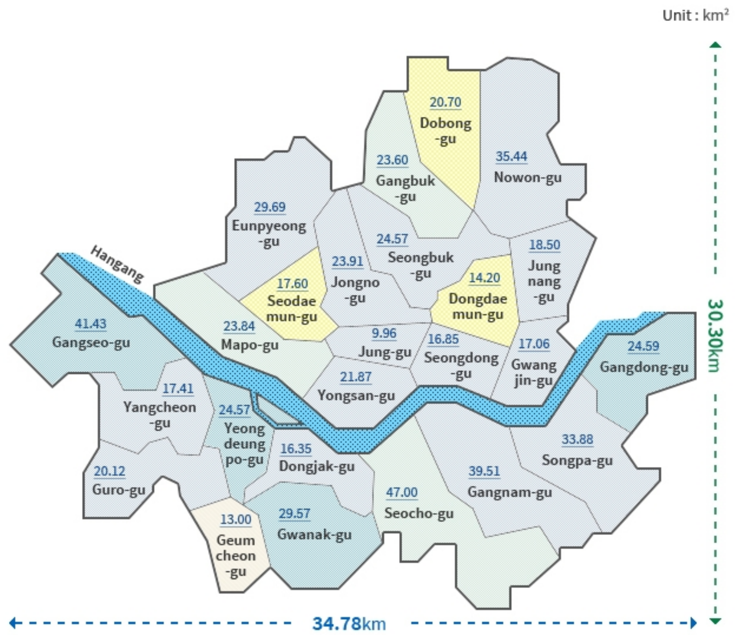

Figure 3- 4 Districts and area of Seoul (Source: www.english.seoul.go.kr)

3.3.3 Coding

Coding is the central analytic procedure in grounded theory. It is used to conceptualise raw data into concepts and categories. There are three types of coding in Straussian grounded theory, including open, axial, and selective coding (Strauss, 1987; Corbin and Strauss, 1990).

Open coding is the initial stage that breaks down the data analytically. It allows the investigator to label events, actions, or incidents as concepts and group similar concepts into categories, offering the building blocks for further interpretation (Corbin and Strauss, 1990; Van Niekerk and Roode, 2009). This first stage in the conceptualisation process is accomplished through line-by-line analysis, whole sentence or paragraph analysis, or perusing the entire document (Strauss and Corbin, 1990).

> *The analytic process through which concepts are identified and their properties and dimensions are discovered in data. (Corbin & Strauss, 1990, p. 101)*

Axial coding closely links to open coding in which the categories and their subcategories are connected through their relationships. It identified the conditions of a phenomenon represented by category in the coding process, examines the specific context, strategies and consequences that relate to the phenomenon. As a result, the complex nature of relationships is systematically captured (ibid.).

> *The process of relating categories to their subcategories, termed 'axial' because coding occurs around the axis of a category, linking categories at the level of properties and dimensions. (Corbin & Strauss, 1990, p. 123)*

Selective coding is the last activity through which core (central) categories are selected by the researcher to form the storyline of a theory. After breaking down the data and generating categories in open coding, organising categories and their subcategories through axial coding, the salient categories need to be integrated to a larger scheme and finally contribute to the theoretical explanation of the research question (ibid.).

> *The process of integrating and refining the theory. (Corbin & Strauss, 1990, p. 143)*

From the above it should be noted that though Strauss stated the coding practice as three different types, they are not distinct, independent methods, but rather a repeated series of activities in the coding process.

The first case study (York, Chapter Four) details the way in which the coding techniques were employed in this research.

3.3.4 Constant comparison

The constant comparison method is another major element of grounded theory. It combines explicit coding and analytic procedures (Glaser and Strauss, 1967). In this way each incident that is coded for a category is compared against another for similarities and differences through a cyclical approach until all the needed concepts are identified (Glaser and Strauss, 1967; Corbin and Strauss, 1990; Strauss and Corbin, 1990). The constant comparative method helps to achieve greater precision and consistency of the conceptualisation process (Corbin and Strauss, 1990). It is a continuous process that works to integrate categories and delimit the theory till the research is completed (Glaser and Strauss, 1967).

The following flowchart illustrates the application of Straussian grounded theory in this research.

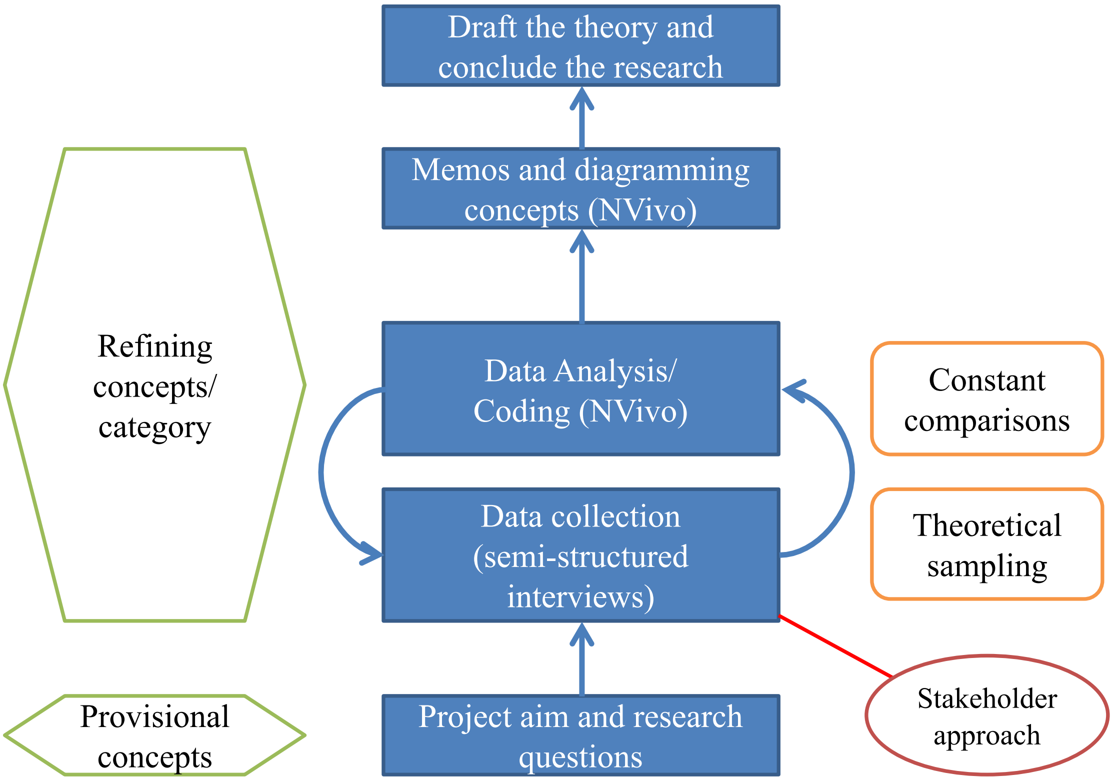

Figure 3- 5 Grounded theory and research process in the study

3.4 Semi-structured interview

Interviews are one of the most popular methods in qualitative inquiry. Qualitative interviewing is an information gathering process that allows the investigator to collect in-depth context about the topic by communicating with research participants (Bryman, 2012). Interview covers a variety of forms that fundamentally ranging from structured, semi-structured, to unstructured interviews. Structured interviews are used more in survey research and quantitative research with specific questions in order, while the other two are widely used in qualitative research and allow a higher level of flexibility and openness. Interviews can be conducted with individuals or groups, in person or remotely via telephone or internet (King and Horrocks, 2010; Bryman, 2012).

This research employed semi-structured face-to-face interviews as the primary method. As an important format of qualitative interviews, semi-structured interviews create a verbal setting for the interviewer to pursue the respondents' perspectives on specific topics and are well suited to grounded theory (Corbin and Strauss, 1990; Flick, 2009; Bryman, 2012). Interviews are flexible and mirror a conversation. They provide space for the interviewer to respond to the emergent issues in the course of the interview by asking follow-up questions, they also give the interviewees more leeway to express their perceptions in their own terms (Bryman, 2012). Yet, unlike unstructured methods, semi-structured interviews have a fairly clear research interest, which is reflected in the interview guide covering the topics under investigation and the process of interviewing. However, the flexible and loose nature of semi-structured conversation means that the designed questions are not necessarily to be followed in an exact way in each interview, and different phrases can be used when asking the questions. Thus, a semi-structured interview allows the interviewer to have more direct control over the conversation and be able to respond to unanticipated directions (King and Horrocks, 2010).

3.4.1 Interviewee selection

The stakeholder approach was used to facilitate the selection process. As outlined in the section 2.3 of Chapter Two, end-user stakeholders of air-quality monitoring are mainly from national, international societies and social groups. Thus, elite policy actors and environmental experts from the following sectors were invited in the three study cities to share their opinions:

a. Governments (environment departments/agencies): government officials who have extensive knowledge about the policy making process in the study city or country,

b. Environmental NGOs: environmental activists who have experience in using the monitoring data to lobby policy makers or organise public campaigns;

c. Academia/think tanks: researchers who have expertise and knowledge of the impacts of environmental policies and the path of technology development;

d. Special interest groups (e.g., charities, foundations)/specialist citizen: activists and specialist citizens who have the knowledge of or experience in air quality issues.

My research recruited interviewees who had relevant experience and expertise, and English-speaking participants were preferred. Although the interview candidates were primarily selected by the researcher through internet search and invited by email, the project partners also provided support, especially for the two cities outside the country of residence. For Berlin, the project partners from Unweltbundesamt (UBA) and the WZB Berlin Social Science Centre (WZB) helped with identifying relevant organisations to approach. For Seoul, the project collaborator from Seoul National University helped to arrange contacts based on the end-user stakeholder map provided by the researcher. The involvement of project partners in the interview recruiting process is not ideal, as it can result in a biased representation of end-user opinions due to the inclination of colleagues, for the case study of Seoul in particular. However, without their support, the data collection would not have been possible. In order to offset the bias, documents and previous studies with respect to air quality issues of the case study city were employed to cross-check the interview data. The project partners also helped with translation and navigating cultural issues. Seoul National University also required a further layer of ethical approval for carrying out research interviews in Seoul. Hence, the involvement of project partners consolidated the ethical underpinnings of this study.

Participation in the interviews was entirely voluntary. In order to achieve maximum participation from the end-user stakeholders and get in-depth knowledge of the topics, groundwork was carried out and snowballing method was employed. In total, 41 informants contributed to the research in the three study cities.

3.4.2 Interview topic guide

The interview guide was prepared to cover the topic areas under investigation. The questions and prompts were designed in the light of the research aim and objectives of this PhD research, the reading of, and identified gaps in the literature, as well as the background of the parent CAPACITIE project. The questions were open-ended, aiming to encourage interviewees to elaborate on their experiences and opinions in their own way. In this way important and/or relevant issues that formed their opinions could be captured.

The topics were divided into four parts with 11 main questions in total. The introduction section, asked about the participants' personal background and expertise, followed by two parts concentrating on their experience and viewpoints with respect to environmental policy and air-quality monitoring technology, ending with an open question for comments or any other issues if applicable. Several probes were considered for each main question, except the last one. Yet it should be clear that the topic guide provided a list of general questions with potential research interest, the exact phrasing in each interview was different, though an attempt was made to ask all the questions and whenever possible to use similar wording.

Part 1. Introduction

One question and three sub-questions were designed to get the participants' profile, outlining who the interviewee is, how she relates to air quality management and to what extent she is aware of environmental regulations.

Part 2. Views of current legislation and expectations

This part had five main questions outlining the interviewees' experience in environmental governance and air quality management.

Part 3. Pollution monitoring technology

This part of the questions sought to uncover the view of the participants on the technology development and the function of air quality data. The questions help to gain an insight of expert opinions on the design of new technologies and provide a vision for future air-quality monitoring practice and potential space for improvements.

In order to provoke the participants opinions on new forms of monitoring technologies, this part of interviewing employed visual images which illustrate both traditional sophisticated methods and emerging air-quality monitoring paradigms. The photos were not intending to present the exact instruments used in the measurement of air quality in practice. Instead, this photo-elicitation technique was used to trigger richer discussions about the technologies as how they were understood by the interviewee (Harper, 2002; Bryman, 2012).

Part 4. Conclusion

One open question was asked at the end of the interview. The participant was invited to share any comments on the study area and to reflect on the responses and discussions.

Finally, a question about potential contacts was asked, as the participation was entirely voluntary, this snowballing technique with reference to particular professional networks helped me to identify the suitable participants for the research. In addition, the interviewee was invited to stay in contact with the researcher.

3.4.3 Process of interviewing

3.4.3.1 Pilot interviewing

The analytical steps of interviewing followed the grounded theory approach. That is to say, current interview material was used to inform the subsequent research interviews, which participants to approach, which areas to investigate and what theoretical concepts to explore in the next interviews. In order to specify the research priorities and orientate the interview participation, I carried out a pilot phase.

The parent project, CAPACITE, covers various environmental pollution issues in cities, involving air, water and noise pollution. It was expected that this study would examine contextual factors and their effects on the development of urban environmental monitoring practices in general. Therefore, four informants from York who were knowledgeable about water quality, environmental noise, and general sustainability issues were invited to share their opinions on local environmental monitoring. Coinciding with CAPACITIE activities, the pilot stage also involved visits to Berlin and Seoul during which communications with project collaborators were established. As the project proceeded, it became apparent that it was overambitious to include three different environmental topics in one PhD project. It was necessary to focus on one topic of interest to all three cities and where more data were available. Consequently, the rest of the study concentrated on investigating issues related to urban ambient air quality. The pilot stage also involved a mapping exercise to understand the regulatory regimes for monitoring urban environment in the three cities (see Appendix I).

3.4.3.2 Interview material

The collected interview material was often a transcription of recorded interview conversation (when permission was given), or written notes. Audiotaping helped to clear the points made during the conversation, correct the limitations of memories, also allowing the researcher to concentrate on the communication to be alert to any emergent topics instead of paying attention on taking notes during the conversation (Bryman, 2012). Therefore, it was a preferred technique in this research. In total, 41 experts informed the research through 34 conversations and one email interview. Among the 34 conversations, four were group interviews due to the convenience of the participants. 32 out of 34 interviews were recorded, of which three were remote interviews, i.e., two by Skype and one by telephone. Additionally, whenever possible any images, texts, instruments, or other object presented by the interviewee were used in the analysis. The materials allowed the respondents to illustrate their views. Therefore, they also helped the investigator to explore the needs of end-users about air quality issues.

The transcription, together with other qualitative documents, were used to detail air-quality monitoring practices in the three cities and contributed to the data coding and analysis procedures. When concepts were extracted from the transcription, NVivo, one of the most widely used Computer Assisted Qualitative Data Analysis Software (CAQDAS) (Bazeley and Jackson, 2013) tools was employed to organise the analysis process.

The interview process helped the researcher to develop knowledge regarding the social-political status quo of urban air quality management as mentioned in the grounded theory. It also facilitated the identification of end-user stakeholders, as interviewees held a participatory role in the wider stakeholder network of urban air quality management. As such, it enabled the researcher to explore end-user stakeholder perceptions as well as the epistemological interpretations of the concept.

3.5 Ethical issues of the research

This research was conducted in an ethical and publicly defensible manner. The interview process ensured the personal respect, dignity and safety of research participants. Before each interview, respondents received background information about the project, the interview topics, data protection and privacy information (i.e., information sheet and topic guide). The participants were required to read and sign a consent form, which outlined the purpose of the interview. When remote interviews happened, verbal consent were obtained. Wherever permission was given, the conversation was recorded. The photos taken by the researcher during interviews were also grounded with permission.

The ethical concerns with respect to culture and language were also addressed. As part of the research was performed outside the home country of the researcher and host institution, the local customs of South Korea were respected. In addition, to overcome the language barrier and respect the participant, there was an interpreter involved in one of the interviews conducted in Seoul.

Furthermore, data and confidentiality issues were addressed. Participation in the research was entirely voluntary, and all the personal data and responses were kept anonymously. Hence, no names, positions, or organisations were disclosed. Instead, code numbers were assigned to each interview participant in order to identify their contributions in this thesis. Original records and related transcripts were stored securely in a password-protected computer and backups were made using a cloud-base system (Google Drive), to ensure the data could be accessed throughout the period of the project. The cloud system was also password-protected. At the end of the project, the data will be transferred to the department for future research or review. As such, the data policy of the University of York was followed (www.york.ac.uk/records-management/dp). Additionally, the translator has signed a confidentiality agreement in order to guarantee the anonymity of the participants and fulfil the data protection requirements.

The ethical issues with respect to the interview background information, interview topics, and participant consent form and recruitment process were approved by the University of York Environment Department Ethical Review Committee. Respective national languages were used for the interview introduction and consent form (see Appendices).

In addition, to respect ethical norms in South Korea, research activities in Seoul were cleared by the Internal Ethics Review Board of Seoul National University to ensure that the research met South Korean legislative requirements. All ethical approvals were periodically reported to the European Commission.

3.6 Conclusion

This study used a qualitative research methodology underpinned by a grounded theory approach, which allowed a critical understanding of air-quality monitoring in cities to emerge. An interview strategy was developed to explore perceptions of end-user stakeholders and the way in which social-political context shaped the deployment of non-conventional monitoring technologies.

Semi-structured interviews in York (UK), Berlin (Germany), and Seoul (South Korea) were carried out with 41 experts from government, academia and social groups. The interviews were coded in line with a Straussian approach to grounded theory. Additionally, an email interview was conducted as part of the European data collection. The following chapters present the analyses of qualitative data gathered for each city case study.

4.0 Introduction

The previous chapter examined the importance of end-user stakeholders in urban air-quality monitoring. It argued that understanding the needs of end-users, and the barriers and benefits to the adoption of non-regulative air-quality monitoring methods is central to establishing effective new monitoring practices. This chapter analyses the function of air-quality monitoring and the factors affecting the deployment of low-cost air-quality sensors in practice, by investigating air quality issues in the city of York in the UK.

The chapter begins by reviewing the socioeconomic profile of York and the legislative background with respect to air-quality monitoring in the city. It then presents the interview data, identifying and focusing on the main themes that have emerged from the interviews. Finally, it relates the case-specific findings back to the role of end-user stakeholders at the end of the chapter.

4.1 York and its air quality policies

4.1.1 York: a unique medieval city in England

York is a walled medieval city with a rich historical and cultural heritage, making it one of Europe's popular tourist destinations, receiving millions of visitors annually[7]. The city centre is located within the inner ring road with several radial routes linking to the outer ring road. There are no major industrial sites in the City of York Council area. The nearest large industrial emission sources are three power stations Drax, Eggborough and Ferrybridge located between 19km and 25km south of the city (City of York Council, 2015a). As for environmental issues, due to its low-lying flat topography and rivers, flood risk is often seen as the main environmental concern of the city following a series of high profile flood events (City of York Council, 2013a; City of York Council, 2013b), for instance, the devastating floods of 2000, 2007, 2012 and 2015 (The Guardian, 2000; BBC News, 2012; BBC News, 2015b; The Press, 2016).

[7] Annual tourism figure for 2014 was 6.7 million according to Visit York survey result (Visit York, 2015). In a most recent government bid, the number quoted is 10 million (City of York Council, 2016c).

Local councils have statutory duties to protect environmental well-being and public health (See Local Government Act 2000 and Health and Social Care Act 2012), and the City of York Council is committed to continuously improving the environment and delivering an internationally recognised ultra-low emission city as a local strategy (City of York Council, 2015c). Yet the existence of historic buildings, narrow canyonised streets coupled with the extra vehicle movements created by tourists makes traffic flow in the city a central concern (City of York Council, 2015b), and the improvement of air quality is an on-going challenge (City of York Council, 2016b).

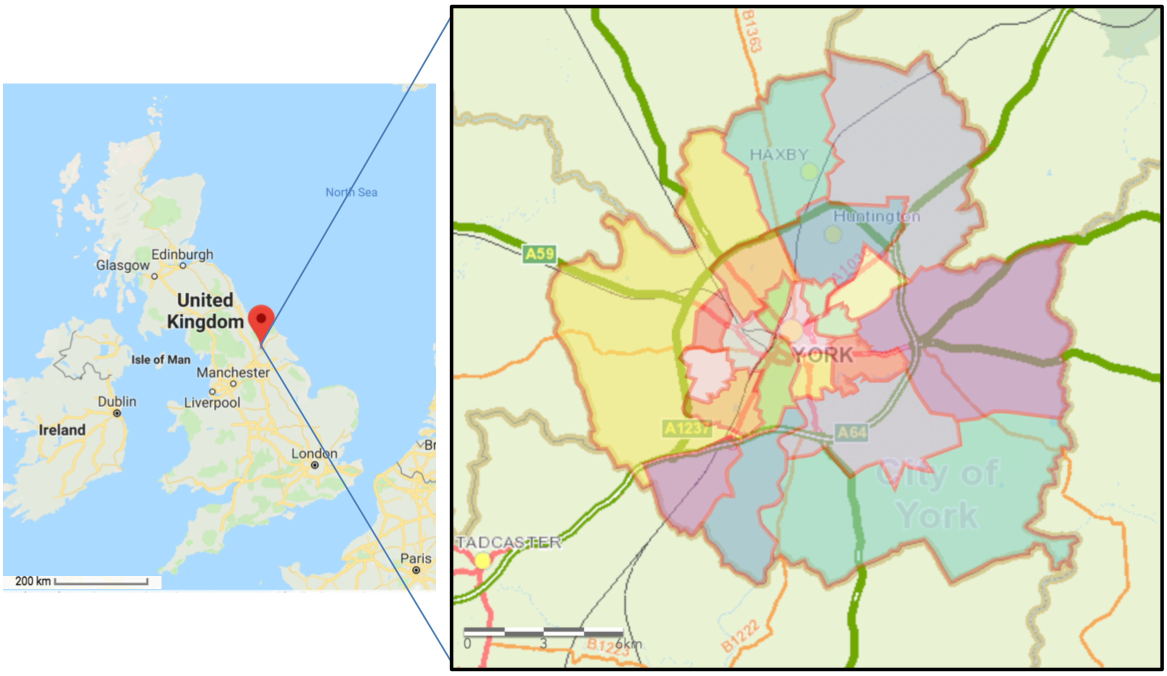

Figure 4- 1 Location of the study city: York, UK (City of York Council, 2019, Google, 2016b)

4.1.2 Legislative background

The European Union (EU) and other international organisations seek to minimise pollution and its adverse impacts on human health and the environment via a range of legislative instruments. Within the EU, the main policy instruments are the Air Quality Directive 2008/50/EC on ambient air quality and cleaner air for Europe[8], Directive 2004/107/EC relating to arsenic, cadmium, mercury, nickel and

[8] Directive 2008/50/EC of the European Parliament and of the Council of 21 May 2008 on ambient air quality and cleaner air for Europe merged the Air Quality Framework Directive 96/62/EC on ambient air quality assessment and management, three daughter Directives, i.e., 1999/30/EC (relating to limit values for sulphur dioxide, nitrogen dioxide and oxides of nitrogen, particulate matter and lead in ambient air), 2000/69/EC (relating to limit values for benzene and carbon monoxide in ambient air), 2002/3/EC (relating to ozone in ambient air), and Decision on Exchange of Information 97/101/EC.

polycyclic aromatic hydrocarbons in ambient air (i.e., the Forth Daughter Directive) and the new National Emission Ceilings (NEC) Directive 2016/2284/EU[9]. While the first two Directives focus on concentrations of pollutants in the air, the latter regulates national total emissions of atmospheric pollutants.

The Air Quality Directive (2008/50/EC) sets legally binding limits which must not be exceeded for concentrations of major atmospheric pollutants such as particulate matter, sulphur dioxide, nitrogen dioxide and oxides of nitrogen, lead, benzene, carbon monoxide, and ozone in the ambient air (Council Directive, 2008). It also proposes two formal ways to manage exceeding levels of pollution:

- Air quality plans that 'should be developed for zones and agglomerations within which concentrations of pollutants in ambient air exceed the relevant air quality target values or limit values, plus any temporary margins of tolerance, where applicable.' ((18), Article 23)
- Action plans that 'should be drawn up indicating *the measures* to be taken in the *short term* where there is a risk of an exceedance of one or more alert thresholds in order to reduce that risk and to limit its duration.' ((19), Article 24).

In addition, monitoring and reporting requirements of ambient air quality are detailed in the Air Quality Directive and Fourth Daughter Directive. These rules involve locations of sampling, measurements methods (known as the reference method), as well as data management and information provision. Directive 2015/1480/EC of 28 August 2015 amended details of several annexes to the Directives, setting more stringent rules on the measurement of atmospheric pollutants (European Commission, 2017a).

Beyond the EU, the Convention on Long-Range Transboundary Air Pollution (CLRTAP) formulated by United Nations Economic Commission for Europe (UNECE) in 1979 (UNECE, 1979) was the first legally binding agreement to address air pollution at the international level and has been extended by eight protocols, each dealing with a specific air pollution problem (UNECE, n.d.).

[9] The new NEC Directive 2016/2284 entered into force on 31 December 2016 and repeals and replaces the original Directive 2001/81/EC, it sets national totals of atmospheric emissions of the key pollutants and sets reduction commitments for 2030 taken by the EU and its Member States.

As a member State of the European Union, and a Party of the UNECE Convention, the UK is required to comply with European legislation and to address issues of long-range transboundary air pollution. The responsibility for implementing government programmes to protect the environment is attributed to the Department for Environment, Food and Rural Affairs (Defra) and the Scottish Government Environment Directorate. At the European and international level, Defra represents the UK's environmental interests at meetings and conventions. In the UK, the Air Quality Directive and Fourth Daughter Directive were incorporated into UK laws through the Air Quality Standards Regulations 2010 (Defra, 2014).

At the national level, the major environmental law in the UK is the Environment Act of 1995 which sets out the requirement for the development of a strategy in relation to air quality in the UK (Defra, 2007). In response to the 1995 Environment Act, on March 12th, 1997, the UK became the first country in Europe to develop a national Air Quality Strategy (Potter, 1997). The Strategy has undergone a series of reviews. The latest version was published in 2007 - the Air Quality Strategy for England, Scotland, Wales and Northern Ireland (Volume 1) (Defra, 2007). It sets out the standards and objectives of air quality and the actions required to reduce the level of atmospheric pollutants in certain circumstances. The Air Quality Objectives include nine pollutants for the protection of human health. They are benzene, 1,3 butadiene, lead, carbon monoxide, sulphur dioxide, nitrogen dioxide, PM10, ozone, polycyclic aromatic hydrocarbons (PAHs). In addition, the National Emission Ceilings Directive (2001/81/EC) is transposed into the National Emission Ceilings Regulations 2002 as a national law. The EU limit values and air quality objectives as set out in the UK National Air Quality Strategy (2007) are presented in Appendix VI.

The devolved administrations have a statutory duty to implement national legal instruments under the Environment Act 1995 (Part IV) and the Environment (Northern Ireland) Order 2002 (Part II) in the UK (City of York Council, 2006). To comply with these responsibilities, local authorities need to undertake a Review and Assessment process, which shapes the cornerstone of the Local Air Quality Management (LAQM) system. In the first stage of the process, local authorities must evaluate the seven air pollutants in the local area and develop actions to address cases where air pollution levels fail to meet the defined objective through designating Air Quality Management Areas (AQMAs) and carrying out Air Quality Action Plans (AQAPs). Ozone is exempt from this process as it is tackled at national level (City of York Council, 1998). The responsible government bodies at national level are the Department for Environment, Food and Rural Affairs (Defra) in England and Devolved Administrations in other parts of the UK, including the Welsh Assembly Government in Wales, the Scottish Government, and the Department of Agriculture, Environment and Rural Affairs in Northern Ireland[10].

4.1.3 Air quality management and monitoring in York

York has struggled to meet the national health-based air quality objectives, in particular with respect to the annual mean limit for nitrogen dioxide of 40 micrograms per cubic metre (ug/m^3) (City of York Council, 2015a; City of York Council, 2016a). In order to comply with the legal duty, the City of York Council (CYC) undertakes regular Review and Assessment processes of local air quality, guided by the Policy Guidance and the Technical Guidance[11] under Part IV of the Environment Act 1995 in England. The first stage Review and Assessment was completed in 1998. A stage two Review and Assessment was required for nitrogen dioxide, sulphur dioxide and PM10 (City of York Council, 1998). In response to the results of the first stage Review and Assessment, the first AQMA declaration was made in 2002 in order to reduce the levels of the three identified pollutants. The second and third stage reviews and assessments were completed in 2000 with continued NO_2 exceedances observed, as a result, another two AQMAs were declared in 2010 and 2012 respectively (City of York Council, 2014, City of York Council, 2015a). In order to tackle the NO_2 problem, CYC has produced three Air Quality Action Plans (AQAPs) in 2004, 2006 and 2015. After implementing the second AQAP, the Council also introduced an overarching Low Emission Strategy (LES) in 2012, in order to support emission reductions for carbon and local air pollutants, mainly NO_2 and particulate matter. The LES was the first of its kind in the UK (City of York Council, 2016a). Furthermore, building upon the two action plans and the LES,

[10] As of April 2016, Defra and (Department for Transport) DfT have set up a joint unit in order to deliver national plans, particularly about NO_2 reduction (Airqualitynews.com, 2016).

[11] The Technical Guidance is published at the UK level, while Policy Guidance is published at the national level, both with the exception of London. The latest versions are the Local Air Quality Management Policy Guidance (PG16) and Local Air Quality Management Technical Guidance (TG16), for details: http://laqm.defra.gov.uk/supporting-guidance.html.

CYC intends to establish the UK's first 'Clean Air Zone' in 2018 and work towards an '*internationally recognised ultra-low emission city*' in the most recent AQAP3 (City of York Council, 2015c), and to provide an *exemplar* of clean vehicle uptake in the UK (City of York Council, 2016c).

Real-time monitoring of nitrogen dioxide and other pollutants has been undertaken at a total of 14 locations across York since 1999. In addition, there are 340 locations of NO_2 diffusion tubes across the city of York, making it the UK's most extensive provincial monitoring network (City of York Council, 1998; City of York Council, 2016a; City of York Council, 2016c). Yet it should be noted that not all the monitoring stations and diffusion tubes are in operation every year. In 2016 nine of the stations and 233 diffusion tubes were in operation, of which the real-time monitoring stations measure nitrogen dioxide and particulates on a minute-by-minute basis, while the diffusion tubes are collected on a monthly basis (City of York Council, 2015a). Geographically six of the running automatic stations are within the local air quality management areas, eight of nine are classified as roadside (<5 m from the kerb) and one is an urban background site (City of York Council, 2016a). The number of diffusion tubes deployed for NO_2 monitoring in York is defined in line with council budget savings as the diffusion tubes were supplied and analysed by other contractors and the decision depends on the Council's financial situation (City of York Council, 2015a; City of York Council, 2016a). The three AQMAs and location of automatic monitoring sites in operation in 2016 are presented in Figure 4- 2.

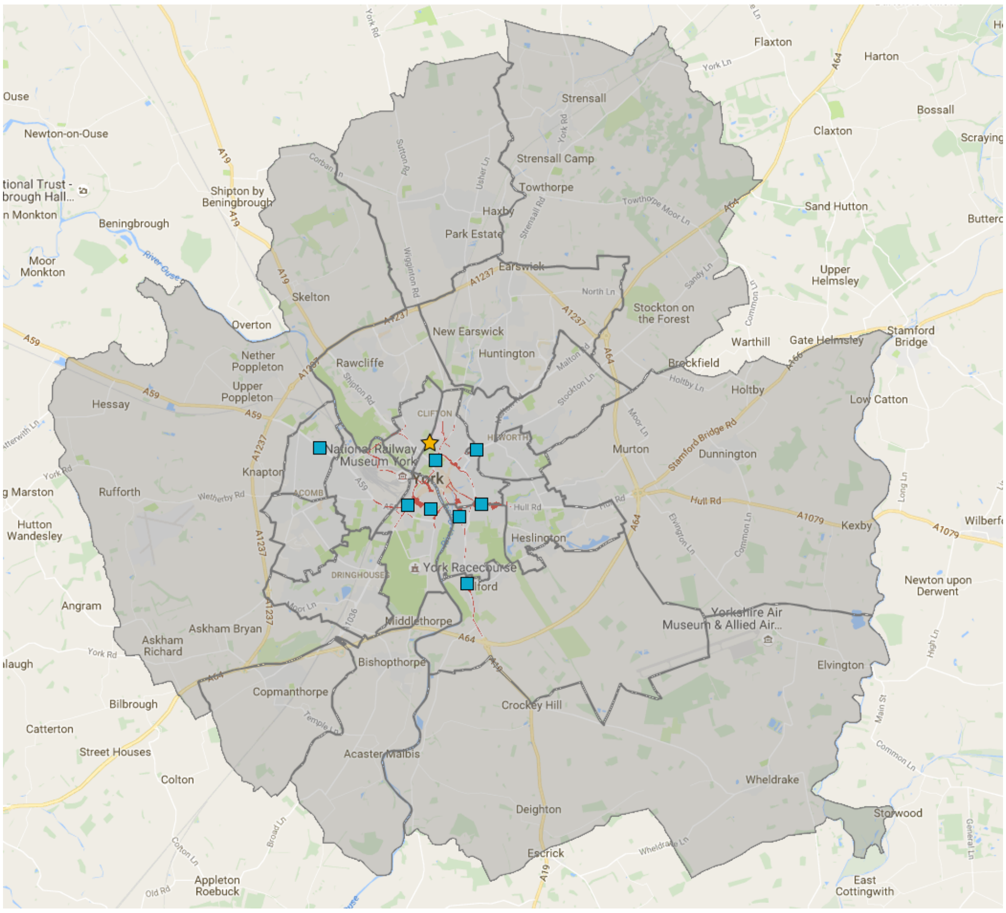

Figure 4- 2 Local air quality management areas (red), background monitoring station (asterisk), and roadside monitoring stations (square) in York (produced in Google My Maps, based on the Council's data)

With respect to the progress of air quality management, the results for York show that most air quality objectives were met after 15 years of implementation of the Local Air Quality Management mechanism in York, and PM2.5 was within the EU target value in 2015. However, nitrogen dioxide, the traffic-related pollutant has continued to exceed limit values (City of York Council, 2006; City of York Council, 2015c; City of York Council, 2016a). Figure 4- 3 is derived from CYC's air quality report illustrating the annual mean of NO_2 from the monitoring station in York from 1999 to 2014 (City of York Council, 2015a). It shows that outside the AQMAs the level of NO_2 has been maintained below the national objective, whilst little or no improvement has been observed after the initial decline in early 2000 within AQMAs, especially after 2005, some of the sites have even shown elevated values.

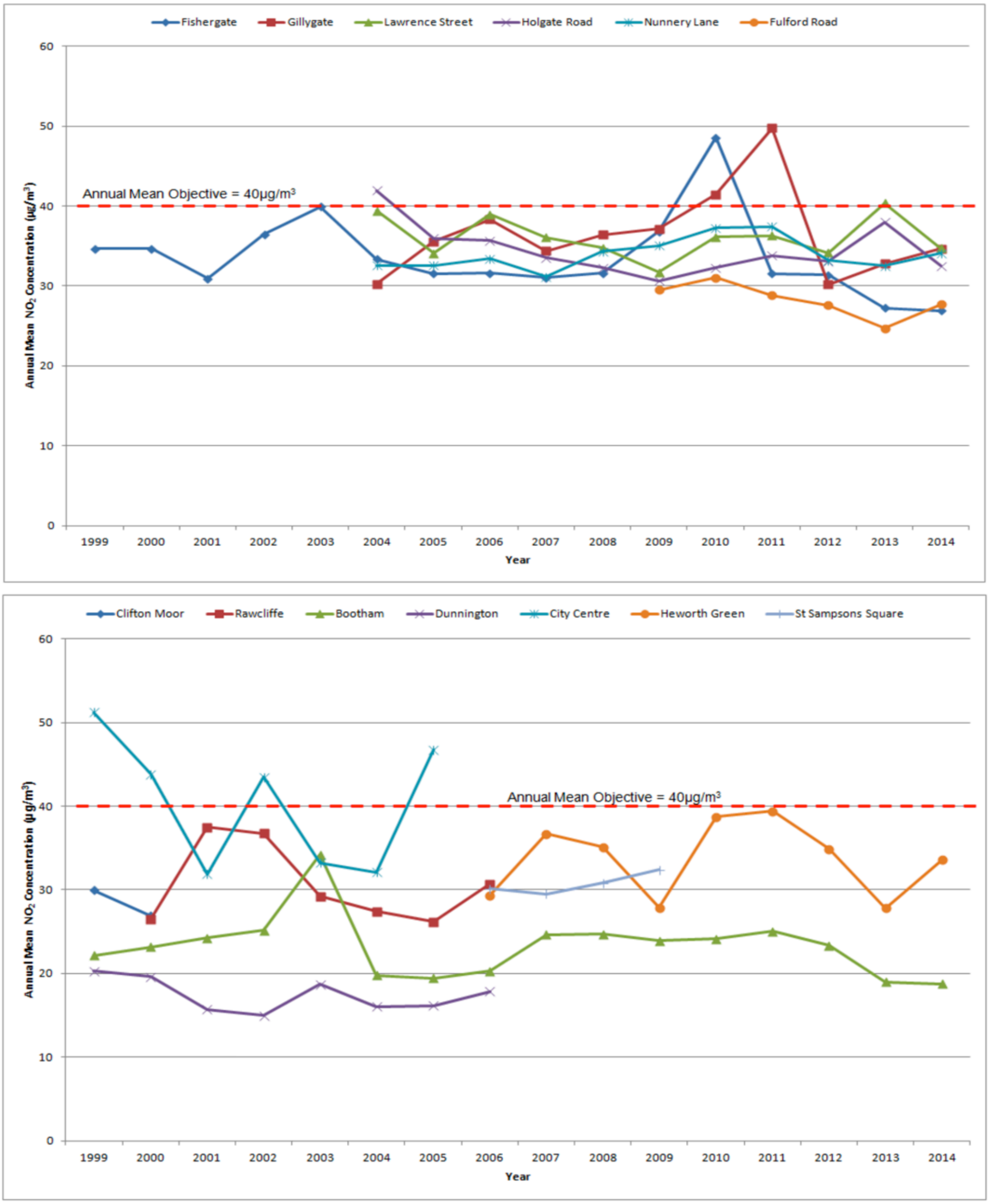

Figure 4- 3 Trends in annual mean nitrogen dioxide concentrations measures at automatic monitoring sites inside (up) and outside (bottom) the AQMAs between 1999-2014 (City of York Council, 2015a)

On the basis of statistics on nitrogen dioxide, the effectiveness of the local LAQM process is arguably limited, even though it has successfully identified three Air Quality Management zones and carried out Air Quality Action Plans as a result of the repeated Review and Assessment work. The Council's third Action Plan (AQAP3) concludes that '*AQAP1 and AQAP2 had failed to achieve an improvement in air quality within the city centre AQMA*' (City of York Council, 2015c).

4.1.4 Information infrastructure and the dissemination of monitored air quality data

There are national and international legislative requirements in terms of information sharing system of air quality. Internationally based on the Aarhus Convention[12], EU laws[13] require the Member States to establish an information infrastructure to make environmental datasets available to the public.

In the UK context, national regulations and policies[14] also mandate relevant national bodies and devolved local authorities to provide the public with air quality information. All the compliance evaluation needs to be submitted to the European Commission and published online (Defra, 2014).

In York, the Council summarises air quality information, its health impacts, policies and consultation documents, as well as a list of air pollution reports on the Council's website[15]. The monitoring stations and downloadable annual reports are available on the air quality website, JorAir[16], which was initially designed for educational purposes. However, the real-time or near real-time concentrations are only possible to access through the national website, Air Quality England.[17] Limited spatial information related to the local air-quality monitoring system is also available on the open data platform[18]. Yet, at the time of reporting, an updated version of the designated website is available. The new version contains latest news regarding local air quality issues and a link to AQ England website on homepage and related assessment reports[19], as shown in Figure 4- 4.

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[12] The United Nations Economic Commission for Europe (UNECE) Convention on Access to Information, Public Participation in Decision-Making and Access to Justice in Environmental Matters

[13] For example, Directive 2007/2/EC of the European Parliament and of the Council of 14 March 2007 establishing an Infrastructure for Spatial Information in the European Community (INSPIRE), Directive 2003/4/EC of the European Parliament and of the Council of 28 January 2003 on public access to environmental information and repealing Council Directive 90/313/EEC, Directive 2003/35/EC of the European Parliament and of the Council of 26 May 2003 providing for public participation in respect of the drawing up of certain plans and programmes relating to the environment and amending with regard to public participation and access to justice Council Directives 85/337/EEC and 96/61/EC, and the Air Quality Directive 2008/50/EC.

[14] For example, the laws applicable to England include but not limited to Freedom of Information Act 2000, Environmental Information Regulations 2004 (EIRs), INSPIRE Regulations 2009 and its 2012 Amendment. There are also other policies: Defra Open Data Strategy, Open data roadmap for the UK, the UK Government Digital Service (GDS) guidelines, and Local Government Transparency Code.

[15] For details: www.york.gov.uk/homepage/28/air_pollution, accessed on 28 August 2015.

[16] York air quality website, www.jorair.co.uk, accessed on 28 August 2015.

[17] Air Quality England, www.airqualityengland.co.uk, accessed on 28 August 2015.

[18] Open Data on public services in the City of York, www.yorkopendata.org, accessed on 28 August 2015.

[19] New version of Jorair website: jorair.co.uk, assessed on 24 April 2018.

Figure 4- 4 Designated website for local air quality in York, old (L) and new (R).

4.2 End-user stakeholders' participation and identification

Despite a well-developed legal framework and political commitment to improving air quality, there continue to be issues in meeting air quality standards in York, in particular in relation to nitrogen dioxide. An obvious question, therefore, is whether the provision of more data on air quality could improve the situation. To determine if there was a demand for greater air quality data delivered through non-regulatory practice, a range of end-user stakeholders in York were invited to share their opinions. The participation of interviewees was driven by grounded theory, with the aim of securing comprehensive knowledge with respect to the topic and achieving the theoretical saturation. Although the researcher intended to reach a balance of participation and representation of interests of different stakeholder groups (see the stakeholder network in Chapter Two Figure 2- 2), this was not reflected through an equal numeric involvement of stakeholder groups, nor the total number of organisations involved in the research. Instead, this was evaluated by the qualitative data that were obtained during the interviews, which were the key factor in deciding when theoretical saturation was achieved.

The identification of participants was guided by stakeholder theory in order to identify and differentiate the end-user stakeholders from other stakeholder groups and attaining an in-depth understanding of urban air-quality monitoring through expert interviews. The local authority had been earlier (Chapter Two) identified as a salient stakeholder in terms of operating and managing the local air-quality monitoring practice. It is also where different stakeholder groups meet together representing various interests and to discuss the impacts of this issue in the city. Therefore, local government was identified as the gatekeeper for approaching local experts. During the interviews, the participants were invited to recommend other experts and comment on the potential beneficiaries of new monitoring practice and the likely benefits they may receive, if any. Snowballing was used to identify new interview participants, mapping out the end-user stakeholders' network in the context of York, and to understand their interests and opinions on the technology development. As local air quality management is led by national policy, informants who have expertise at the national scale were also interviewed.

In order to facilitate the analysis and the presentation of the findings, the research participants were assigned an identifying code (see Chapter Three). The code represents the study city, and the chronological order e.g., Interviewee_Y1, meaning the first informant that participated in the York study. A full list of participant identity codes in York is listed in Appendix V. Personal information of the participants was anonymised. The qualitative data collected through expert interviews were then coded and analysed using Nvivo.

4.3 Coding and the development of themes

This section presents the coding process and issues that emerged from the interviews with 17 participants from the York study between August 2015 and June 2016. The informants include local authority employees, local politicians, environmental scientists, as well as representatives of environmental pressure groups, for instance, environmental non-government organisations and individual lobbyists.

4.3.1 The process of coding and interview analysis

The data analysis started with open coding in line with a grounded theory approach. Open coding was initially used to gain an overview and to make sense of the interview data by assigning a word or phrase to each textual passage (where relevant) to summarise the data, which were transcribed audio recording or written notes. In this process, data that were not directly relevant such as general conversation, interruption of others, or where the information strayed off topic, were reduced and were not taken into account in the generation of initial codes.

The initial codes, or nodes in NVivo, were constantly updated throughout the data collection and coding process. The emergent information and findings identified during each of the interviews would modify the codes, and also helped identify the subsequent interview participants and guided areas of further enquiry. Through constant comparison during the coding process, theoretical saturation was achieved. Examples of the open coding process are provided in Table 4- 1.

Table 4- 1 Example of the initial open coding for the York study.

Interview transcript	Initial code
Interviewee_Y1 ***So that's [carbon emission] the overriding concern. I think I would probably rate air pollution next for all the reasons, all the health reasons that we have caught on and the need, and that largely witness, some of them would be dealt with via the carbon policies, some reduction policies, a lot more is, … to do with the way we manage transport, and I would want to see road pricing as the way of managing the way we use petrol cars and the lorries, and encouraging more rational more environmental responsible behaviour.***	• Priority of environmental issues • Awareness • Impact • Carbon policy • Transport policy • Source of emission • Vision on air quality control measures • Economic instrument • Behaviour
Interviewee_Y14 ***I don't really think we need more data necessarily to meet air quality legislation. I think we know enough in many aspects. But it's more a research question: if we're concerned about personal exposure more, that's an emerging issue, then that requires very different measurements. There's certainly an absence of those sorts of measurements. So depends on the context, when you look at, say European regulations, they are actually quite strict and very prescriptive about where you should measure what you should measure. But that's a very narrow focus. If we're worried about the wider health impacts of air***	• Efficiency of current monitoring • Function of monitoring • Potential use in research • Gaps in current practice • Motivation of non-stationary monitoring (potential use) • Legislative requirements • Prescriptive • Perspective of uses • Challenge for new practice, impacts • Function of new monitoring

pollution, then really I think we probably need different sources of monitoring.

An extensive list of codes was generated as a result of the open coding process. Many of them reflect similar ideas or connect with a bigger topic, for instance, lacking personnel and budget are related to the impact of austerity upon the local authority, the local transport policy is one element of the transport management, and data reliability and the lack of political willingness indicate the challenge for taking up new air-quality monitoring practice. The initial codes were, therefore, collated and grouped into code categories via an axial coding process, i.e. identifying the links of the open nodes, combining them into categories through the relationships established between and across codes. The following Figure 4- 5 illustrates one of the code categories, on the 'state and progress' of air-quality monitoring and management in York. The description of the code category is presented in the text box on the left, and the number of sources shown in brackets, i.e., 13 of the 17 participants shared their opinions on the air quality control policy.

State and Progress

- Legislative context of managing local air pollution
- Policy development over time and progress of the agenda
- Factors that affect the effectiveness of air quality management in York
- State of air quality monitoring technologies and communication channels in York
- Perceptions of monitoring, emerging monitoring technologies
- The use of generated air quality data and information provision

Local air quality management policy (13)	Monitoring and communication (13)
Air pollution property (2)	Austerity (5)
Awareness (13)	Availability of data (7)
City layout, traffic condition (8)	Benefits and beneficiaries of using portable device (6)
Cultural, behaviour, social perception (11)	Challenge, critiques of non-stationary monitoring (11)
Governance capability (9)	Efficiency of regulatory monitoring (7)
Impact of air pollution (12)	Function of monitoring (11)
International influence (3)	Information and communication (6)
Local leadership (3)	Leadership in changing monitoring practice (5)
London (7)	Political willingness (5)
National and local division (4)	Vision on AQ monitoring and communication (10)
Organizations (4)	
Policy consistency (5)	
Policy development and agenda (12)	
Policy implementation (6)	
Prioritisation and political willingness (5)	
Pollutants (12)	
Resources (10)	
Science and vehicle technology (9)	
Scope of legislation and identified gaps (9)	
Vision on AQ management (8)	

Figure 4- 5 Example of a developed code category on the context and progress of air-quality monitoring and management in York.

Subsequently, the interview records were re-coded utilising the newly formulated code categories, and further integrated into focussed code categories in the selective coding stage. By the end of selective coding, significant emergent categories were identified for understanding the issue of air-quality monitoring in the city of York. In addition, the topics and data that did not fit within the selected code categories were removed from further analysis, for instance, comments on sustainable transport and air quality issues in Asia were not considered as important themes for interpreting air quality issues in York. These selected code categories became the main themes and whilst they represent discrete topics they are nevertheless connected and related to one or another. They also provided a useful guideline for analysing the data of the other two study cities. The emergent themes are addressed in section 4.4.

It should be noted that whilst open coding, axial coding and selective coding provide three stages in a grounded theory approach (Strauss and Corbin, 1990), in this case they were not used in an explicitly sequential manner. Indeed, to a great extent the three steps overlapped, especially the open coding and axial coding stages, as new insights were gained from the interview materials and the definition of core variables changed along the data collection and analysis (detailed in Chapter Two). The process was also an iterative one, consequently the themes emerged from several stages in the research.

4.4 Emergent themes

This section expands on the themes that emerged from the data as a result of the iterative coding process, giving the background, justification and insights gained from the interviews. Even though the themes are addressed separately, it should be noticed that they are not discrete but rather are interconnected and overlapping.

4.4.1 State and progress

Theme description

State and Progress refers to the legislative requirements on air-quality monitoring and management, as well as the current situation with respect to the monitoring network and communication practice in York. Specifically, it covers:

- policy development and progress of air quality agenda,
- emission control policies (especially transportation),
- the political system and organisations with respect to the monitoring and management of air quality,
- perceptions of the development of monitoring techniques, and
- use of generated air quality data and information provision.

A recurrent topic mentioned by the interview participants was the way in which air quality is managed in York. All the participants were invited to comment on air quality policies, any successful and unsuccessful aspects in York, where applicable (as some of the participants were more familiar with the issue at national scale). The effectiveness of air pollution control policy, and transport management in particular, emerged as a major area of concern for all participants. Meanwhile, air-quality monitoring was perceived as an activity that follows legislation and serves policy making. Hence, it was decided at a later stage of the coding process to integrate established air-quality monitoring practice into the same category as air quality policies in order to formulate an overview of the status quo in York. This theme expanded upon the issues raised by the stakeholders, highlighting the links between the air quality control policies and the measurements.

As addressed earlier, the effectiveness of the Local Air Quality Management (LAQM) process is limited on the basis of nitrogen dioxide readings (see section 4.1.3). Interviewees made similar remarks, commenting that the measures did not deliver the improvements as expected, '*very little actually happened*' (Interviewee_Y1), and the identification of hotspots are not promoting changes: '*we've got more air quality management areas, we've got more technical breaches; so we've got the laws but we're still no further*' (Interviewee_Y2). But does that mean the LAQM in York is a policy failure? How can these findings be explained? Does air-quality monitoring play a role?

It was widely recognised by *all* the participants (13/17) who were focusing on air quality issues that road traffic is the main source of air pollution in York, particularly with respect to the problem of NO_2, which is the key pollutant of concern in York and across the UK. Participants repeatedly raised the fact that how transportation is managed is critical to lowering emissions. That is to say, the issues of transport policy were used to justify the lack of effectiveness of the LAQM, largely thanks to the problem of congestion in the city and the use of diesel vehicles.

The particular city profile has been recognised as a challenge when addressing congestion in York. First, it has been noticed that the compact city centre of York is an old walled area with narrow streets and historical buildings. This physical layout restricts options for improving the road network and congestion within and around the inner ring road. It also creates street canyons where the atmospheric pollutants cannot disperse, resulting in high concentrations of air pollution when traffic is heavy (Sini et al., 1996, Vardoulakis et al., 2003, Baik et al., 2007). Secondly, even though York is small, it is a popular tourist city and weekend destination for stag and hen parties due to its wide mixture of tourist attractions, pubs, shops in a walkable area (Interviewee_Y4, Y5). In order to tackle the congestion problem and reduce the traffic volume inside the city, the local administration had brought in policies to stop the expansion of car parking in the city centre and introduced Park and Ride services at the city boundary. York's Park and Ride service is an incentive parking scheme which encourages car users to leave their vehicles at designated car parks at the outskirts of the city and continue the journey into the urban areas by public transport (City of York Council, 2005). Since the first permanent Park and Ride site at Askham Bar opened in 1990, York's Park and Ride service has been recognised as one of the most effective in the UK (White, 1996, City of York Council, 2005, York City Council, 2010). Yet, there has been no decline on the total volume of vehicles driven in York, and an increase in diesel car numbers and net inward flow of trips has been observed (City of York Council, 2012). The historic background, street layout and high volume of traffic all contribute to on-going air quality problems in the city:

> *I mean so the main problem York has is it's quite a small city with very compact streets and very congested, because we don't normally have our own population, we have a big student population, we have a lot of visitors; so it's a very small city trying to bring a lot of people in every day which causes a lot of congestion, a lot of standing traffic, and not a lot of options to deal with it, because you can't just go and knock down ancient walls, monuments, etc. So it is quite a tricky problem really for us [Interviewee_Y5]*

Besides the traffic congestion, another topic repeatedly addressed by the local experts was the exhaust emission of diesel vehicles. As road traffic is a major contributor to poor air quality in York, it was expected by the local authority that the improvement of vehicle technology through increasingly stringent exhaust emission standard (vehicle type approval)[20] could deliver a reduction on the level of nitrogen oxides (NOx) (City of York Council, 2006). However, the problem with current laboratory testing standards of diesel cars show that the nitrogen oxide emissions are much higher in real-word driving conditions (Transport., 2016). The technical problems with diesel engine vehicles also increase the level of NO_2 concentrations on road, as NOx can be transformed to NO_2 through photochemical process in the atmosphere (Carslaw and Beevers, 2004; Carslaw and Beevers, 2005).

[20] All motor vehicles in Europe need to meet specified performance standards through the process of 'type approval' in which the sample vehicles represent a 'type'. The standards cover all aspects of vehicle design. The one regulating tailpipe emissions of passenger and commercial vehicle is referred as 'Euro' standards (VCA, 2018).

The issue was later on specified in the Council's report as a '*failure of current vehicle emission standards*' which was one of the factors responsible for the exceedance of NO_2 limits (City of York Council, 2015a). In response, York's overarching Low Emission Strategy and new Air Quality Action Plan have been developed to encourage the uptake of low emission vehicles, and to promote the use of alternative modes of transport and tackling congestion in the city (City of York Council, 2012; City of York Council, 2015c).

In the context of Local Air Quality Management, air-quality monitoring is perceived as providing data that indicates the status of air quality, identifies pollution hotspot where action is required and is primarily used for the purpose of complying with the legislation, from the methods used in monitoring to the reporting:

> *… monitoring data is vital, you need that evidence base to change policy, and that's obviously what's really crucial that comes from that. [Interviewee_Y8]*
>
> *It's a key part of developing the evidence based on air quality, the air quality levels, its impacts and so forth, and in terms of compliance, demonstrating compliance with the legislation. So air-quality monitoring is crucial, it's also crucial in terms of evaluating the impacts of measures that you put in place. [Interviewee_Y13]*
>
> *Measurements are very very important, you know without them, we are nowhere, the epidemiology that determine health impacts of air pollution, that's all from measurements, they underpin everything. […] So we use the measurement that, I mean it has to by law make measurements in certain conurbation over certain size, so it has to do that to meet European Directives. And it has to report to Europe in a regular way as well, so it's required by law to do that. [Interviewee_Y14]*

Yet, although meeting the legal requirements and informing policy have been identified as primary functions of air-quality monitoring, how the evidence could be used beyond these regulatory purposes was also widely highlighted by the experts. Different purposes outlined in the interviews include: for research purpose (Inverviewee_Y6, Y10, Y14), for environmental education and public engagement (Interviewee_Y1, Y2, Y5, Y10, Y15, Y16, Y17), as well as for raising political willingness (Interviewee_1, 8, 16, 17). These uses of air quality information are closely linked to the dissemination and communication of air quality measurements provided by established monitoring practice which are also issues commented by the participants, for example:

> *[the Council] put them on the website anyway, people want them, but they're not particularly easy to read by a member of the public. [Interviewee_Y5]*
>
> *They say, we've got these monitoring sites, we've got these test tubes up around the city, we've got monitoring stations, yes we know we're in technical breach, we're working on it. But you think well what, what are the levels, to find out what the levels have been in the city, as far as I can see you have to wait till a report comes out kind of a year, hence, there is no daily levels. [Interviewee_Y2]*
>
> *The problem is that it all relies on people sort of going and finding it for themselves. [Interviewee_Y16]*

Although a lack of air quality information and communication channel has been identified when addressing the uses of air quality information, is there any link to the efficiency of local air-quality monitoring? Does it affect the effectiveness of Local Air Quality Management in York? What are the other factors that should be addressed? The following themes were raised from the *state and progress*, aiming to establishing the link and investigate the underlying issues.

4.4.2 Power and influence

Theme description

Power and influence refers to the capability of end-user stakeholders in terms of introducing any change in monitoring and managing local air quality activities. Specifically, it covers:

- possession of resources which are needed to establish air-quality monitoring practice and implement control measures,
- legitimacy and political influence with respect to local air quality management,
- development and challenges in terms of taking-up new monitoring technologies, and
- how the impacts of non-regulatory monitoring are perceived and what interests do end-user stakeholders have.

The theme developed around the comments on who *has* the power to *influence* air-quality monitoring and management in York, and what are the costs and benefits of introducing any change. It involves not only who possesses power, but also which end-user stakeholder groups *do not hold* the resources to enact power and change. It can be considered to have two fragments: first, power and influence on air-quality monitoring, and second, power and influence on the progress of emission reduction. Both of them are used in its broadest sense to refer to the current situation and possible future development, linked to the role of technology innovation and different purposes of *uses* of air quality data.

The participants' perceptions of the function of air-quality monitoring are closely aligned with the legislative requirements (linked to the theme state and progress). As addressed earlier (section 4.1.2), there are two tiers of legislation with respect to air quality management in the UK: the central government at the top where the national policy is developed for meeting EU air quality limit values and objectives, and the local authorities underneath who are responsible for making local air quality management policies in response to the UK national air quality objectives.

Given that background, there are two levels of air-quality monitoring in order to fit the different purposes. First, there is the national network, AURN (Automatic Urban and Rural Network), operating by several contractors on behalf of the UK Department of Environment, Food and Rural Affairs (Defra) and the Devolved Administrations, with the main purpose of complying with the EU Air Quality Directive. Second, there are monitoring sites run by local authorities to fulfil their legal duty and to support the Air Quality Management Area (AQMA) as required in the Local Air Quality Management (LAQM) system. Currently two of the nine real-time monitoring stations in York are part of the AURN network (Figure 4- 6), one is an urban background site (Bootham), and another one is roadside station monitoring urban traffic (Fishergate). All automatic monitoring sites can be found in Figure 4- 2.

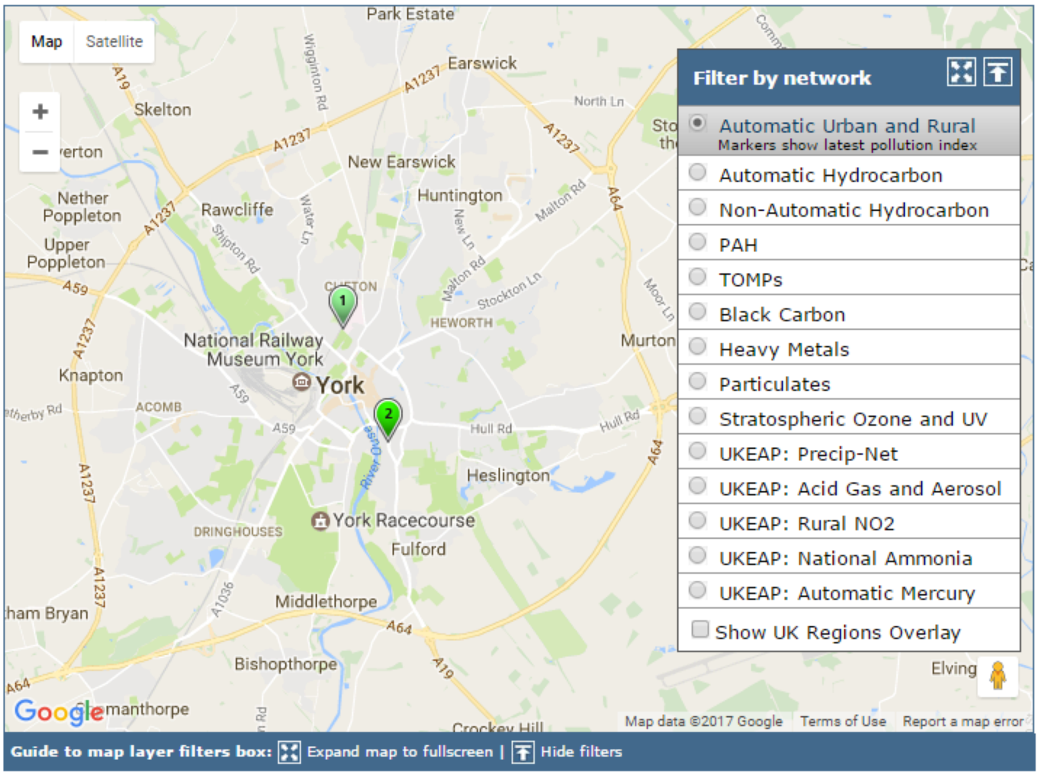

Figure 4- 6 Location of two real-time air-quality monitoring stations of Automatic Urban and Rural Network (AURN) in York[21], Bootham (urban background station, 1 on the map), and Fishergate (roadside station, 2 on the map).

Hence, although local authorities have the legal duty and authority to carry out air-quality monitoring, the scope of their work with respect to non-AURN sites is subject to the local administration:

> *Many local authorities have other sites as well, which isn't part of the national network, and they can place those where they want to suit their local needs, and their local needs are somewhat different with the national scale needs. [Interviewee_Y13]*

As mentioned earlier, '*their local needs*' are driven by LAQM to identify the hotspots and can be affected by several factors. Possessing sufficient resources to operate and maintain monitoring network was raised as an influential factor and austerity was identified as one of the constraints (Interviewee_Y1, Y2, Y4, Y5, Y7, Y9, Y10, Y15, Y16, Y17). For instance:

> *The other big problem for everybody at the moment is resources because there is just no resource to do air quality work properly; it's a huge issue for local authorities at the moment. […] we've lost our monitoring officer, we don't have a single person dedicated to our air*

[21] Retrieved from uk-air.defra.gov.uk/interactive-map, accessed: March 6, 2017.

pollution stations anymore, we've had to cut back on our diffusion tube monitoring massively, we've had to take on consultancy work to try and pay to keep our jobs. [Interviewee_Y5]

So this gets at the problem of local council often only monitor in one or two places cos it's expensive, and what you want to do is to see what the exposure is… [Interviewee_Y9]

The above examples highlighted two aspects: first, personnel, which refers to the technical staff who perform monitoring and manage the equipment; second, financial resource that supports the deployment and operation of monitoring stations, which was also noticed in the Council's report briefly indicating that the number of diffusion tubes employed is '*in line with council budget saving*s' (City of York Council, 2015a). Nevertheless, it has also been recognised that the monitoring network in York is sufficient to meet current legislative needs (Interviewee_Y5, Y10):

I think in York we have enough at the moment, it might not stay that way […] At the moment in York we are very well, as a local authority we have a very good network, an excellent network; it's not the same for all local authorities [Interviewee_Y5]

So if you take, put London to one side then York has taken the issue seriously, it has got good monitoring and modelling in place [Interviewee_Y10]

As addressed previously, the fundamental function of air-quality monitoring is to provide the evidence for policy making. In case of having the evidence, what are the barriers that limit the effect of LAQM? Other issues emerged in the interviews were largely political, raised by 12 participants, involving implementation (Interviewee_Y6, Y8, Y9, Y10, Y15, Y17), the structure of government organisations and capacity (Interviewee_Y2, Y4, Y9, Y10, Y17), political leadership (Interviewee_Y5, Y7, Y15), and policy consistency and political willingness (Interviewee_Y1, Y4, Y5, Y6, Y7, Y8, Y9, Y14, Y15, Y17) in managing local air quality. These issues are directly linked to the second fragment of the theme: power and influence on the progress of emission reduction.

With respect to the emission sources, as addressed in the previous theme state and progress, road transport was highlighted by all the participants as key reason for technical breaches of NO_2 limits in York. Linking that to the remaining air pollution problem in the city, the participants have recognised that the local administrations often lack the power to control sources of air pollution.

First, Environment Departments often do not have control over other units such as development of energy or transportation, locally and nationally (Interviewee_Y16, (The Environment, 2016)). For example, at national level the lead department in terms of improving air quality is Defra, while the Department for Transport (DfT), is the main authority that allocates grant schemes to funding low emission vehicles, together with the Department for Business, Energy & Industrial Strategy through Office for Low Emission Vehicles (OLEV, 2016). Locally, air-quality monitoring and reporting is currently managed by the Public Protection Unit, while the city transport planning is led by the Transport Planning Unit. Second, although reducing road transport emissions is a problem that needs to be solved locally, it does require national support. The local administration, for example the Transport Planning Unit of York, does not have the power to change the diesel vehicle fleet on the road (Interviewee_Y7) (Barnes et al., 2014), but due to the number of visitors coming to York, it is an important source of local air pollution. It requires a clear cross-departmental national strategy and adequate distribution of power and flexibility to better implement and reduce the emissions, especially when it relates to road traffic[22]. As quoted by the Environment, Food and Rural Affairs Committee (House of Commons, 2016):

> *…if local authorities were able to solve air quality problems using their own powers … . they would have done so already.*

While lacking power to enforce actions and funding resource has been long recognised as one of the main hurdles to lowering pollution level (Hayes and Chatterton, 2009; Defra, 2013; Barnes et al., 2014), it also affects the motivation of local officers engaging in their daily work with concomitant impact upon the effectiveness and capacity of local administration. For instance, the national department offers

[22] The researcher is aware that in response to UK's air pollution problem, a new joint unit between the Department for the Environment, Food and Rural Affairs (Defra) and the Department for Transport (DfT) was officially established in April 2016. The primary issue for the Joint Air Quality Unit (JAQU) is to deliver national plans to improve air quality in order to meet national NO_2 emissions as required under the EU's Air Quality Directive 2008. And around a third of the staff is drawn from DfT with the remaining two-thirds from Defra. Yet, the establishment of JAQU happened after the majority of the interviews for the York study (two were carried out after April 2016), and it was early to comment on the effectiveness of their work. For details about JAQU and the recent funding scheme (released in October 2016):
www.parliament.uk/business/publications/written-questions-answers-statements/written-question/Commons/2016-10-25/50278/
www.publications.parliament.uk/pa/cm201617/cmselect/cmenvfru/665/66504.htm
laqm.defra.gov.uk/laqm-faqs/faq137.html

grants in case the local authority intends to introduce low emission vehicles to local fleets, but that modal shift can only happen if the local authority can secure funding (Interviewee_Y2, Y7). Respondents suggest that as a result of the austerity and inadequate authorisation:

> *a lot of their aspirations have been cut off down to (a lower level); there used to be, you know, a sustainable transport department and it's got whittled down and whittled down over the years. So that they're very, they're struggling to keep the basics going.* [Interviewee_Y15]

York Council's comparative lack of power in relation to London was also raised. Apart from the scale the problem, in terms of air quality, there is no evidence that air pollution has received the same level of political attention and discussion as in London. One of the reasons might be, as commented by one of the respondents in York:

> *in the national picture York's not important, and that's very tricky, and balancing that is very difficult trying to keep interest and support and money, …. If you're a London authority where clearly the government accepts there's an air quality problem it's potentially easier (…), but if you're here up in York where the central government's going: 'bye, not a problem', and you're sat here going: 'well actually yes there is a problem', that's very difficult to deal with.* [Interviewee_Y5]

Meanwhile, there was reflection indicating that the local pro-environmental groups feel powerless when engaging the public:

> *…no-one's interested in this, it's really dull, it's really, really dull and the public, very understandably and accurately, recognise that it's not going to affect them so why should they be interested? [Interviewee_Y15]*

As such, the availability of air quality information was seen to influence the local air quality policy by raising public awareness to promote behaviour change, and accordingly influence political awareness and willingness. With the availability of new techniques, the end-user stakeholders are perceived to have the responsibility to better present the concerns on air pollution (Interviewee_Y8, Y17).

Figure 4- 7 outlines how the interpretation of '*power and influence*' evolved in the interview process. It highlighted how the understanding of emerging concepts was shaped by applying grounded theory, for instance, how the idea was explored in interviews in order to achieve theoretical saturation.

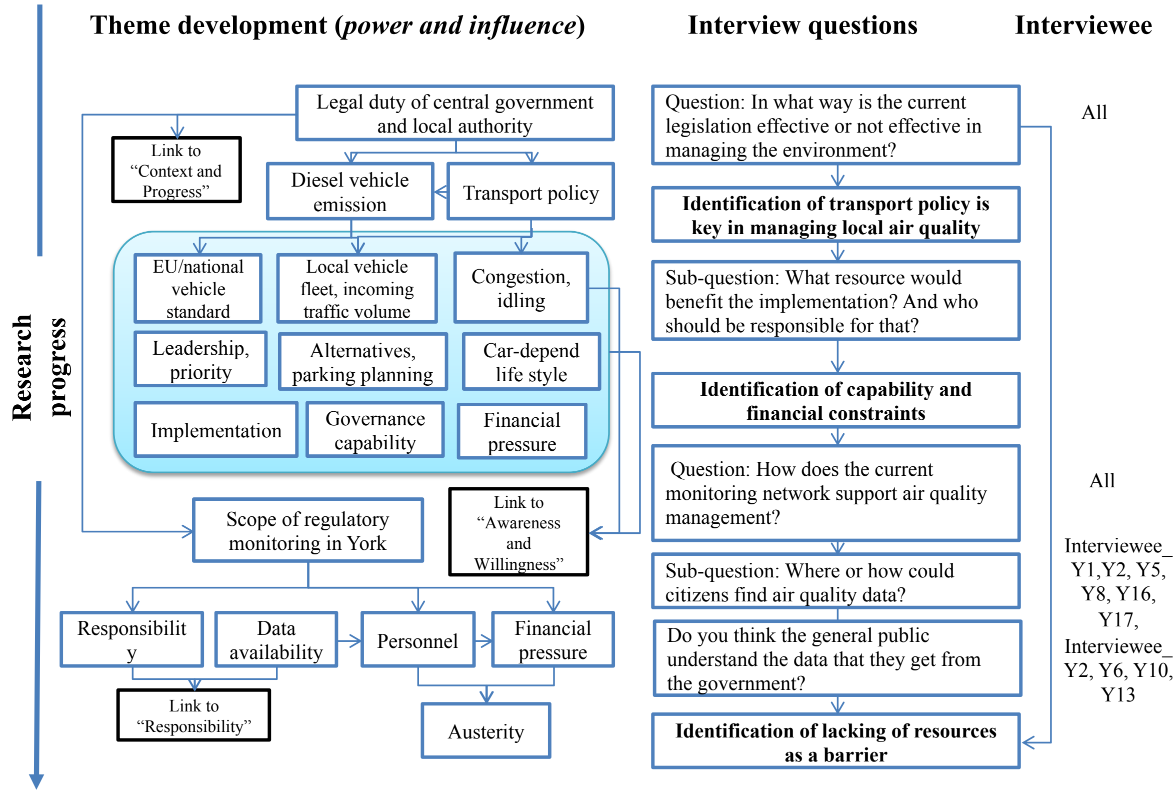

Figure 4- 7 Demonstration of how the theme 'power and influence' was evolved and how austerity was explored in the interview process by applying grounded theory in York

4.4.3 Responsibility

<u>Theme description</u>

Responsibility refers to the liability and duty of end-user stakeholders in managing local air quality, it emerges from:

- possession of resources which are needed to monitor and/or improve air quality,
- distribution of impacts and accountability of the management organisation,
- scales of responsibility due to the impacts of air pollution (for example, local or national, personal).

This theme is closely linked to the previous one of '*power and influence*' and requires an understanding of which end-user stakeholders have the power to influence air-quality monitoring and management;

how they perceive the function of air quality information; and what their accountability is given their powers.

First, although governments are responsible for meeting EU and national requirements, there is a difference between national and local governments. As addressed earlier, Defra represents the UK regarding air quality issues in the EU and central government is liable for meeting air quality limit values, while local authorities have a statutory duty to meet national objectives. However, that does not necessarily mean that the central government has to pay the penalties for breaching the EU Air Quality Directive. Instead, local authorities are required to solve the problem and face penalties in case of infringements in practice. The interviewees clarified:

> *…it (Defra) devolves that requirement (meeting EU limit values) down to the local authorities, … (in case) any fines that come along as a result of not meeting the objectives they (Defra) can pass on to local authorities.* [Interviwee_Y5]
>
> *So that if the EU Commission gets a billion-pound fine or half a billion-pound fine against the UK government, the UK government is going to shuffle that off on to local councils to pay, which is just bowling, just bowling. So, it is awful. [Interviewee_Y7]*

The above examples highlighted that there is a perception amongst participants of how government's responsibility is subverted by reference to the distribution of governance capability and liability, and the attendant challenge that local governments face. The *influence* of *power* on the reduction of air pollution is dependent on what the local administration is authorised to do and the extent to which it is supported at national level, as discussed in Section 4.4.2.

Second, there was a general consensus that air-quality monitoring serves policy making. Therefore, managing the air-quality monitoring-network is ultimately dependent upon the requirements of air quality legislation and management plan. To deliver air quality plan effectively requires collaboration within local government:

> *They also need to do that in the context of other, you know, in context of the development plans for the city, the transport planning for the city, those all need to be joined up to have strategies in terms of the development of the city. [Interviewee_Y10]*

It's that kind of, trying to do that job which the Council really should have done, […] they've a very complicated, within the council there's so much diplomacy and so much politics internally so it, sometimes they find it very hard to get a coherent single message out. [Interviewee_Y15]

However, the change of administration and organisational structure can affect the implementation of air quality policy and consequently, its effectiveness in improving the situation (Interviewee_Y4, Y5, Y9, Y8, Y10, Y15, Y17).

In addition, interviewees' perceptions of responsibility also include the duty of general road users. Some participants suggested that motorists should share the responsibility of pollution reduction (Interviewee_Y1, Y2, Y15). However, cultural and social stumbling blocks exist:

The interesting thing about air pollution in particular is that it's a very democratised form of pollution […] most people drive cars so most people are complicit in it so most people don't see it as a sort of a scandal, something that's being imposed upon them. [Interviewee_Y15]

It's much easier to sort out few big power stations than it is, I mean there's over 30 million vehicles in the UK. And it's, they are all at different ages, all driven differently, maintain differently, different fuels, you know it's highly complex, it is a big challenge not surprisingly to make big big changes there to the entire fleet. [Interviewee_Y14]

While marketing (fuel duty, parking price) should be a guiding force in reducing the traffic volume (Interviewee_Y1, Y2, Y8, Y17), public awareness of air pollution emerged as one of the main reasons for diverse opinions of end-users on air-quality monitoring technologies. Issues related to the awareness of air pollution are detailed in the following theme.

4.4.4 Awareness and willingness

<u>Theme description</u> *Awareness and willingness* refers to both political and public awareness and willingness. Specifically, it covers: • knowledge of the availability of air quality information channel and how that information is perceived, • understanding of the adverse impacts of air pollution and willingness to change the behaviour, • policy priority and political willingness to tackle air pollution.

This theme addresses another aspect that largely underpins the participants' views on urban air-quality monitoring and management. It can be illustrated in two layers: the perceptions of the public and of the politician. It should be noted that here the general public understanding is mirrored by the experts' experience and knowledge.

4.4.4.1 Public awareness and willingness

All the local participants felt that to a certain extent general public awareness of air pollution is limited in York. Although concern is growing due to the increasing mass media's coverage in recent years, the residents in general are not '*bothered'* about air quality (Interviewee_Y1, Y2, Y5, Y7, Y8), and being invisible was identified as the main reason:

> *But invisible, that's really the challenge I think you've got is this invisibility of the situation. [Interviewee_Y8]*

Invisibility and insufficient awareness of air pollution is not limited to York. In the UK the impacts of air pollution on human health have only recently started to attract media coverage (BBC News, 2011, The Guardian, 2017), with the legal challenge raised by ClientEarth (European Commission, 2014b, BBC News, 2015a, ClientEarth, 2016), and the move by newly elected London mayor Sadiq Khan to make air quality an issue of his term of office (Greater London Authority, 2016), as well as the diesel vehicle emission testing fraud (The Guardian, 2015, BBC News, 2015c). Yet, to what extent that concerns people is different. A typical example given by the respondents concerned how the issue is discussed at national level or in London:

> *…in London at least air quality is the environmental issue of greatest concern to Londoners, what we don't know is whether people living outside London share that concern. [Interviewee_Y16]*

According to the participants, even though people are aware of the problem of congestion and want to improve it, does not mean that they are aware of the impact of traffic on their health, for instance:

> *I think people would be more concerned about congestion than they are about the impact of the traffic on their health; I think they worry more about being delayed and being slowed down than they do about the environmental impacts of that traffic, so. [Interviewee_Y5]*

4.4.4.2 Political awareness and willingness

According to the participants, at local level solving air quality is not a real priority compared to housing, employability and economic growth (Interviewee_Y8). Even though improving traffic congestion has been identified a key issue in York as it affects local business and is a considerable concern of residents, it might involve radical actions thus become *'politically unacceptable'* and *'a reversed decision'* (Interviewee_Y17). These comments are related to a traffic control measure implemented in York. The Council administration in office from 2011 to 2015 initiated a scheme aimed at mitigating congestion in York and reducing traffic emissions. The scheme involved introducing a six-month trial traffic ban on one of the main routes, Lendal Bridge, coming into the city centre from 10:30am to 5:00pm from August 2013, giving priority to pedestrians, public transport and cycles (City of York Council, 2013a). The trial was stopped in April 2014 and attracted significant media attention and critical comments at local, regional and national levels (The Press, 2013; BBC News, 2014). This failed attempt to deal with congestion has led local politicians to be wary of new ventures: *'politically now it's very difficult for any party to put forward something which looks like something where [there] would be fuss about it'* (Interviewee_Y17).

Another challenge that many local authorities like York may face is that even though awareness of the adverse impacts of air pollution has improved, it is to a certain extent deemed a 'London-only problem' and therefore receives insufficient attention both politically and socially outside the London area.

To summarise, the frustration of accessing and understanding air pollution measurements limits local residents' ability to recognise the problem and its impacts on health (McDonald et al., 2002). The absence of awareness may then lead to a low level of public pressure, resulting in a weak driver of building up political will to take governmental actions. So how can citizens and the government be better informed in order to promote behaviour change and political decisions? Will the new form of monitoring technology contribute to addressing local air quality issue? The next theme has a focus on the potential role of new forms of monitoring techniques in such matters.

4.4.5 Technological innovation

<u>Theme description</u>

Technological innovation refers to the potential impacts of new sensing technology on managing local air quality, it involves:

- availability and features of non-regulatory air quality sensing technique,
- concerns about the challenges of the innovation,
- potential functions, cost and benefits.

In order to attain the goal of being an ultra-low emission city, CYC intends to extend the existing air monitoring network in order to enhance the evaluation mechanism of delivering the most recent transport plan and air quality action plan. To do so, the Council is looking at the possibility of introducing new air-quality monitoring technologies by deploying a hundred small, multi-parameter and real-time wireless AQ sensors across the city (Figure 4- 8). The vision is that York will have the highest density monitoring network worldwide, becoming 'a World leader in new pollution sensing technologies' (City of York Council, 2016c). For such practice, not only the measurement performance but also more contextual features affecting the installation, such as the connection to power supply, need to be considered (Reed, 2017). Yet, through the rapid development of sensing technologies, even individuals can perform the measurements at home or on the move (Steinle et al., 2013; Bales et al., 2014). With the ambitious strategy and evidence that the Council is open to innovations in place, to what extent those new technologies can contribute to any improvement on air quality management?

Figure 4- 8 The prototype of real-time wireless air-quality sensor (L) (City of York Council, 2016c), and the deployment on the lamppost on campus of the University of York in York (R)

Firstly, there are critiques concerning data quality and the legislative underpinning of such practice. The current air-quality monitoring-network and equipment are subject to European and national laws and guidelines (Council Directive, 2008; Defra, 2007, Defra, 2009). The location, measuring methods, and quality assurance and quality control (QA/QC) procedures are all regulated. By contrast, using new monitoring technologies is beyond the scope of the legislation, and no QA/QC process is required. Hence, the data generated using new technologies are difficult to evaluate and therefore this application would not fit with the legislative monitoring aims leading to concerns about the utility of the data (Lewis and Edwards, 2016).

Besides the data issue, one respondent also argued that more data could probably prove there is a problem but fail to present a solution, as the Council is aware of the problem already, more data could lead to greater work (Interviewee_Y1).

However, these data might provide a useful and powerful source of information (Muller et al., 2015; Devarakonda et al., 2013). It would help people to be engaged in solving the problem as they are co-generating the data and reading the measurements, instead of passively receiving information from the government or agencies. As a result, a better understanding and proper protection measures might be achieved. Such data may provide the *'alarmism for people to actually wake up'* (Interviewee_Y8). Moreover, it could support politicians so that they can call on local government administrations to prioritise the issue. One of the challenges in managing local air quality is that the key pollutant, nitrogen dioxide, is invisible. Engaging with technologies and getting access to understandable information on air quality would contribute to the enforcement of management policies. Without having the pressure from constituents, it hardly can be a priority for politicians, '*…when their (MPs') mailbox start filling up, when people start coming to their surgeries, when people start saying they are concerned, they start taking you seriously, otherwise it's just not there on the agenda.*' (Interviewee_Y8). '*Ultimately it comes down to the political will*' (Interviewee_Y17).

4.5 Linking the grounded theory themes

This section brings together the analyses of the themes and explains the links between them in the context of York. The grounded theory themes are: 1) state and progress, 2) power and influence, 3) responsibility, 4) awareness and willingness, and 5) technological innovation.

The theme of State and Progress refers to the status quo of local air-quality monitoring practice and relevant legislative requirements for local air quality. This theme provides the basis for discussion on air-quality monitoring and reflects the impacts of stakeholder actions as well as policy initiatives. The effects of end-user activities and policy interventions may vary due to the diversity of resources and mixed levels of capabilities held by a range of end-user stakeholders. These resources, capacities and impacts are captured by the theme - Power and Influence. The concept of State and Progress is, therefore, connected with Power and Influence through the influence of a range of stakeholder activities, including those of the government and non-governmental actors. Responsibility extends the discussion of Power and Influence, further elaborates the liability or duties, as well as accountability of end users given their powers. These two themes are closely linked, underpinning the capacity and capability of different end-user stakeholders.

Technological innovation elucidates air-quality monitoring practice from the perspective of the availability of non-conventional monitoring techniques, the cost and benefit of adopting new monitoring practices and possible scenarios of application. Such applications may modify current monitoring practice and consequently affect local air quality. Therefore, the theme is associated with State and Progress. Furthermore, who possesses such monitoring techniques and how the techniques are used are issues of power and responsibility. As such, the theme of Technological Innovation has connections with the theme of State and Progress, as well as the theme of Responsibility and Power and Influence.

While the material and political resources possessed by varied end users define to what extent the end-user stakeholders could affect the conditions of local air, the actual actions towards pollution abatement and changes in the monitoring practice are determined by how air pollution is perceived by these actors and how much are they willing to respond to the situation. Awareness and willingness reflect such ideological stances of the public and the of the politicians. The theme also explains the possible uses and how the data could potentially be interpreted. Hence, Awareness and Willingness is regarded as a central theme connecting the underlying factors of local air quality monitoring and management.

The five themes are the outcome of the coding process of grounded theory and are interconnected. The themes collected in the York study were used as orienting concepts, and the exact meaning of the themes may differ in the other two cities. At the end of the third case study, the subjects included in each of the themes are accumulated. Hence, the broad scope of the themes enables the analysis of local air quality issues covering prospective topics in heterogeneous urban settings.

The following Figure 4- 9 presents the relationships between these concepts in York.

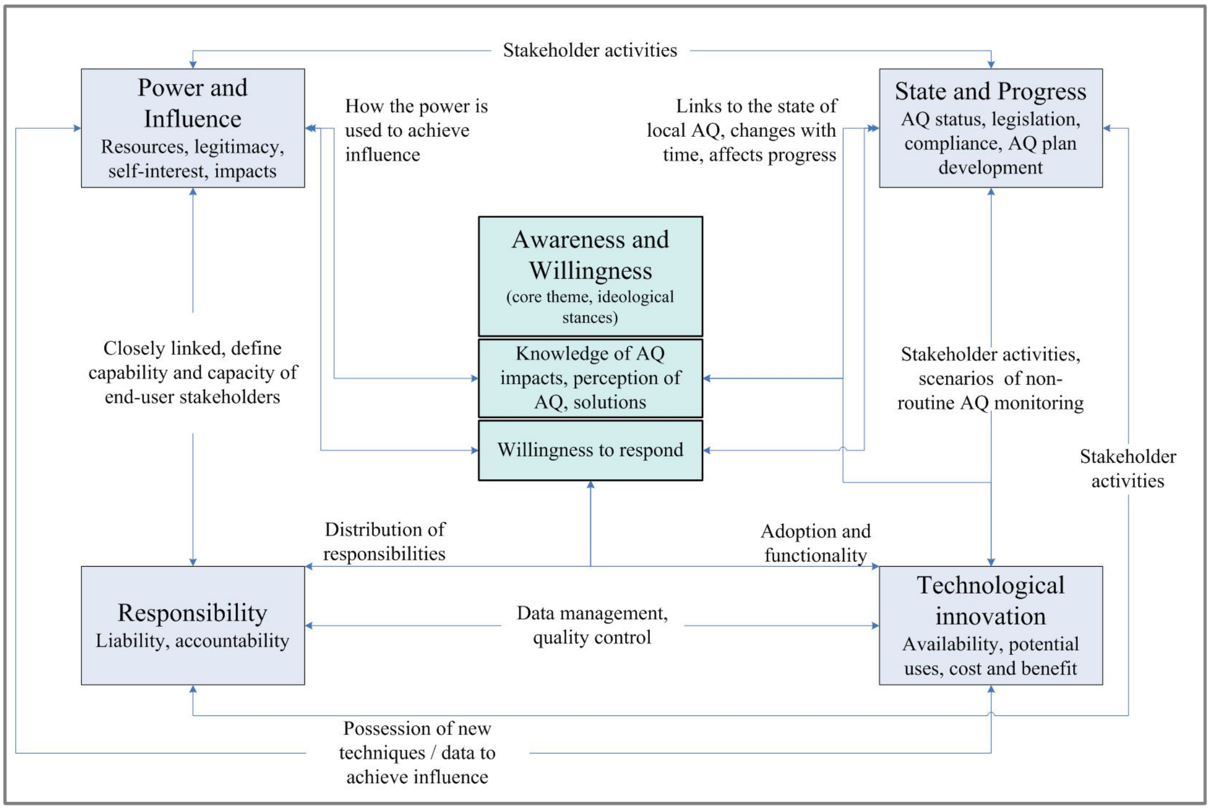

Figure 4- 9 Relations between the developed grounded theory themes in York

The theme State and Progress outlines the political context of local air quality management. Overall, York struggles to meet the NO_2 limit values which is largely due to the challenge in reducing exhaust emissions. Politically, according to the interviewees, the failed Lendal Bridge traffic ban has increased political worries by local politicians about any new radical measures to control road transport emissions (Willingness). Meanwhile, the respondents also indicated that there is a lack of public awareness of local air pollution, resulting in a low level of public pressure on local authority to take actions. Furthermore, austerity emerges in York as an influential factor constraining air-quality monitoring practice (Power). As such, the progress towards reaching air quality objectives is limited. The interviewees suggested that air pollution is an invisible problem with limited political salience in the city.

This case study shows that among five identified grounded theory themes, Awareness and Willingness is implicated in the other four concepts, i.e., State and Progress, Power and Influence, Responsibility and Technological Innovation. Awareness and Willingness also underpins the relations between the themes. Therefore, it was highlighted as the core theme. The analysis of collected data suggested that individual understanding of air-quality monitoring in fact reflects how people perceive local air quality and how it is managed (state). The interviewees commented that public awareness in York is relatively weak and it is associated with the feeling that air pollution is invisible (state). The interviewees suggested that the general public's level of willingness to change car-dependent lifestyle is also limited. According to the participants, such public opinions negatively affect the political will to address local air pollution issues. Consequently, limited levels of public awareness and political willingness became barriers hindering the progress of air quality policies.

The concept of Power and Influence revealed the resources required in local air-quality monitoring and management, who holds powers and what the impacts on local air quality improvement are. In York, the City of York Council is responsible for operating the local air-quality monitoring-network and meeting national air quality objectives. Yet, the number of monitoring sites could be constrained by budget and manpower. With respect to emission management, the main source of concern in York is road transport. Although local government has the power to implement control measures to manage local transportation, it does not have the legal competence to influence the vehicle fleet. Besides there might be a lack of political will to introduce restrictive transport policies due to concerns about potential public reactions. For instance, there was a strong backlash in York when traffic was banned on Lendal Bridge (City of York Council, 2013a; The Press, 2013). Whilst the problems about the traffic ban emerged as much from the implementation of the policy as the policy itself, the clear sense amongst council workers was that this negative experience has limited the scope for similar experiments in the short term. Meanwhile, the findings revealed that environmental activists have experienced frustration and powerlessness as a result of the relatively low public interest in and awareness of local air quality. Unlike in London, air pollution has not received public and political attention and interviewees felt that there is a biased understanding of air pollution as a London-only problem among York citizens.

Determining who is responsible for monitoring and managing local air quality is also complicated. Interviewees in York suggested that conventional air-quality monitoring and management are widely recognised as the legal duties of the government. Still, the participants noted the complexity of governance due to the distribution of liability between different levels of government at national and local levels. Interviewees suggested that in order to achieve air quality objectives and keep local government accountable for improving local air quality, adequate national support is required with clear enforcement mechanisms across departments and internal collaboration at the local level. Furthermore, responses in this case study indicated that respondents believe that car users are also responsible for lowering local air pollution due to the contribution of road transport to the high levels of NO_2 in York. Yet, there is a perception that car owners seem to be more concerned about congestion rather than air pollution and its health impacts. This attitude is captured in the theme of public awareness and willingness.

There were mixed responses on the question of the availability of new tools for measuring and sharing air quality knowledge. On the one hand, there were concerns about data quality and data management for new monitoring practices. Unlike current official monitoring networks that are based upon European and national regulations, there is no legal requirement for using emerging low-cost air-quality sensors. Hence, such devices are not currently used in official routine monitoring. Furthermore, some of the participants questioned the necessity of having more air quality data since the existing monitoring network is capable of demonstrating poor air quality, therefore, they argued that expending energy on reducing emissions is more important (State and Progress, Responsibility). On the other hand, the findings revealed the advantages of deploying ubiquitous monitors and their potential benefits. Involving the public in monitoring could potentially make more citizens aware of the problem and take necessary personal protective actions when the pollution exceeds certain level. The user-friendly interface of new technologies also makes understandable air quality information accessible to the public without needing to make as much effort as is currently required to access the Council's data dissemination system. As such, the use of emerging air-quality sensors could positively promote public awareness and willingness and push for enforcement of emission control measures. The findings also indicated that the administration of York is interested in demonstrating the usability of real-time wireless air-quality sensors to supplement the existing network.

4.6 Chapter conclusion

This chapter presented the empirical findings from York. The methodological process involved the application of grounded theory and semi-structured interviews, drawn from local experts and participants within the UK air quality management system.

In total 17 participants informed the research, including four experts on non-air issues in a set of pilot interviews. The remaining participants were end-users of air quality data and recipients of information as classified in Chapter Two and were part of the end-user stakeholders as mapped out in Section 2.3.

The application of grounded theory led to five key themes emerging from the coding exercise: 1) State and Progress; 2) Power and Influence; 3) Responsibility; 4) Awareness and Willingness, and 5) Technological Innovation.

Each theme emerged from the analysis of the interview data was then used as an umbrella concept in order to establish a narrative for investigating the contextual factors of using air-quality monitoring technologies in York. The case study revealed that routine monitoring practice can be affected by legal requirements, local government's financial capability and the availability of expertise, but lowering emissions is more complex. The findings suggest that a good level of knowledge about air pollution, challenges, solutions, and willingness to address the barriers are key to the effective use of air-quality monitoring as a tool in managing local environments. Therefore, Awareness and Willingness was identified as a core theme that cuts across and links all the themes. These themes are taken as guiding themes for the subsequent case studies. The following chapter turns to the second EU case study of Berlin.

5.0 Introduction

This chapter presents the finding of the Berlin case study, which focuses upon the role of air-quality monitoring and the potential for deploying new monitoring techniques in Berlin.

Section 5.1 presents the profile of Berlin and the legal background of air-quality monitoring in the city, which is covered by the EU's Air Quality Directive. Section 5.2 introduces the end-user stakeholders in Berlin and how the participants were approached. Section 5.3 discusses the interview data starting with the themes developed from the York study in order to determine if there were consistent issues that emerge across these two cities. The findings suggest that the York themes are applicable to Berlin in the broadest sense. Yet, combining the findings of York and Berlin reveals that the awareness of self-responsibility in pollution abatement supports the explanation of contextual factors that affect end-user perceptions of emerging air-quality monitoring. The themes of awareness and willingness, and responsibility are modified accordingly. Finally, the themes are linked in section 5.4, which further reflected the effect of social-political context on the use of low-cost air quality monitors by different end-user stakeholders. The results of the thematic analysis regarding the air-quality monitoring are summarised in section 5.5.

5.1 Berlin and its air quality policies

5.1.1 Berlin: one of the most populous capital cities in the European Union

Berlin is the capital city of the Federal Republic of Germany. The city has a population of more than 3.4 million, which is the second largest urban agglomeration in Germany after Ruhrgebiet, and is the fifth most populous city in the European Union (Amt für Statistik Berlin-Brandenburg, 2017, European Commission, 2016). The city sits on the North German Plain, on the banks of the rivers Havel and Spree, and is about 80 km away from the Polish border (Senate Department for Urban Development and the Environment, 2014).

Berlin has several distinctive features compared to other German and European cities. Politically, it was transferred from a divided metropolis to a constituent state (Länd) with a polycentric structure after German reunification in 1990 (Senate Department for Urban Development and the Environment, 2014;

Senatsverwaltung für Stadtentwicklung und Umwelt, 2015). With respect to economic activity, Berlin is one of the most popular city destinations in Europe (more than 12 million visitors in 2016) (Amt für Statistik Berlin-Brandenburg). Yet, it is the only EU capital where the GDP per inhabitant falls below the national average (European Commission, 2016), which may have implications for the allocation of financial resources in environmental management.

With respect to air quality, Berlin has achieved a degree of success in environmental management, e.g., the SO_2 concentration dropped by 90% between 1989 and 2002 and has stayed below the limit since then, and many of the EU Directive 2008/50/EC limit values are being met. Nevertheless, managing the concentrations of PM10 and NO_2 remains a major challenge for Berlin (Senate Department for Urban Development and the Environment, 2014).

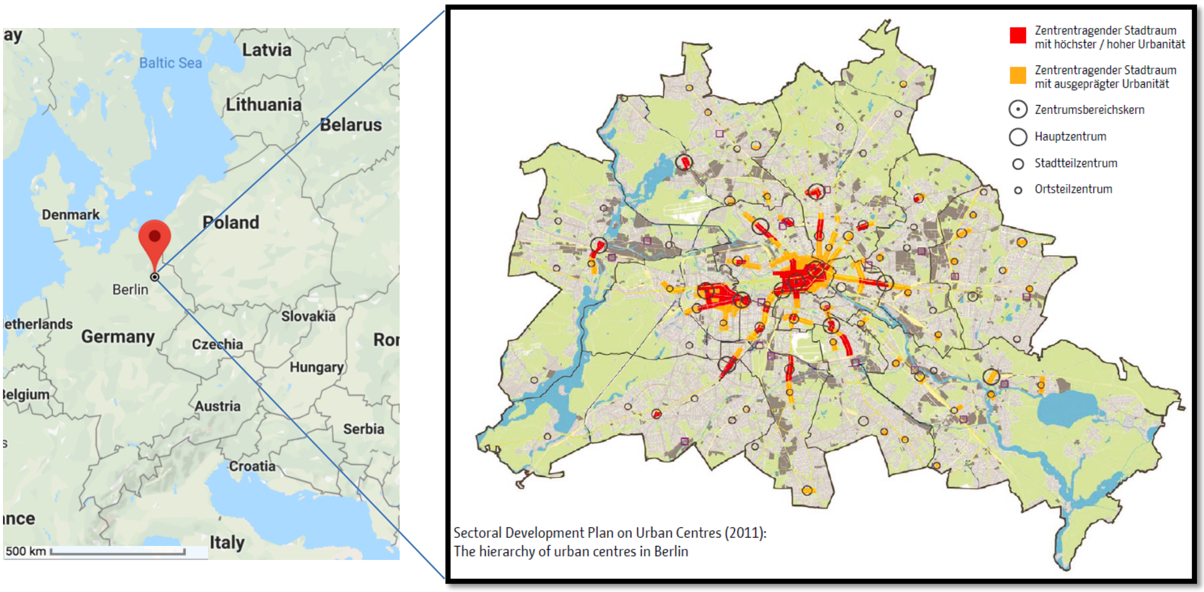

Figure 5- 1 Location of the study city: Berlin, Germany (Google map, L; Senatsverwaltung für Stadtentwicklung und Umwelt, 2015 R, scale 1: 50 000)

5.1.2 Legislative background

German air quality policies are well-established and often serve as an exemplar for other countries to develop their own. Being a member state of UNECE and the European Union, the UNECE Convention on Long-range Transboundary Air Pollution and EU air quality directives all apply to Germany. The legislative competence of environmental issues is shared by the federal government and the states' government (Länder level). The main federal authorities that are responsible for environmental monitoring (excluding natural conservation) are the Federal Ministry of Environment, Nature Conservation and Nuclear Safety (Bundesministerium für Umwelt, Naturschutz, Bau und Reaktorsicherheit, BMUB), and the Federal Environment Agency (Umweltbundesamt, UBA). At state level (Länd), the Senate Department for the Environment, Transport and Climate Protection (Senatsverwaltung für Umwelt, Verkehr und Klimaschutz)[23] of Berlin is the government body dealing with air-quality monitoring and management in the city.

In terms of the legal framework, the main legislation that addresses air pollution problem in Germany is the Federal Immission Control Act (Bundes-Immisionsschutzgesetz: BImSchG) [24] and its implementing ordinances as well as administrative regulations. The Act entered into force in 1974 and has undergone a series of amendments. The most recent change of the Act was made in July 2016.[25] The eighth amendment to the Federal Immission Control Act and the 39th Implementing Regulation to the Act (39. BImSchV)[26] transposed the EU 2008/50/EC Air Quality Directive into German law in 2010 (Senate Department for Urban Development and the Environment, 2014). The Technical Instructions on Air Quality Control, TA Luft [27] are amongst the most important administrative regulations in terms of air quality management, as they set air quality standards, emission limit values of stationary sources as well requirements for the model calculations and simulations in Germany. In addition, there are

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[23] Former Senate Department for Urban Development and the Environment (Senatsverwaltung für Stadtentwicklung und Umwelt) as referred in the Air Quality Plan for Berlin 2011-2017 (Rauterberg-Wulff, 2014).

[24] a) Act on the Prevention of Harmful Effects on the Environment caused by Air Pollution, Noise, Vibration and Similar Phenomena (Gesetz zum Schutz vor schädlichen Umwelteinwirkungen durch Luftverunreinigungen, Geräuschen, erschütterungen und ähnliche Vorgänge).
b) 'Immission' is used in German legislation which is legally defined as 'air pollutants, noise, vibrations, light, heat, radiations, and analogous environmental factors affecting human beings, animals, plants, or other objects' to the effects of emissions on the environment. With regard to air pollution control, this means the effect of air pollutants on plants, animals, human beings and the atmosphere.' Source: www.bmub.bund.de/P678-1, accessed: 20 April 2017.

[25] Last amended by Article 3 of the Act, 26 July 2016. Source: Available at: www.bmub.bund.de/N1912-1, accessed: 20 April 2017.

[26] Article 39 Implementation of Intergovernmental Agreements and of Decisions of the European Communities, 39. BImSchG

[27] First General Administrative Regulation Pertaining the Federal Immission Control Act (Technical Instructions on Air Quality Control – TA Luft) of 24 July 2002 (GMBl. [Gemeinsames Ministerialblatt - Joint Ministerial Gazette] p. 511) (Technische Anleitung zur Reinhaltung der Luft – TA Luft), available at: http://www.bmub.bund.de/fileadmin/Daten_BMU/Download_PDF/Luft/taluft_engl.pdf, accessed: 20 April 2017.

specific administrative regulations on certain pollutants from a certain type of emission sources (Ordinance Implementing the Federal Immission Control Act), e.g., the Ordinance on the Limitation of Hydrocarbon Emissions during Refuelling of Motor Vehicles (21. BImSchV).[28]

5.1.3 Air quality management and monitoring in Berlin

As required by European and national legislation, particularly the EU Air Quality Directive and the Federal Immission Control Act, the city state of Berlin has to conduct compliance assessments and prepare air quality plans once exceedances of limit values have been detected. The first exceedances of NO_2 and PM10 against EU limit values were detected in 2002, the same year that European legislation[29] listing air quality limit values and assessment requirements was transposed into German law (Senate Department of Urban Development, 2005). Yet, the monitoring network had been set up much earlier: Berlin had established the system (Berliner Luftgüte-Messnetz, BLUME) in 1975 (Senate Department for Urban Development and the Environment, 2014). As of September 2016, the network consisted of 16 fixed stations that measure the concentration of certain air pollutants on a five-minute basis, and in addition, there are 30 small samplers that were added in 1997 as supplementary to the BLUME network, of which 23 are in operation. Furthermore, the authority also operates one meteorological station and one mobile measurement station (Senate Department for Urban Development and the Environment, 2014; Berlin Environmental Atlas, 2015).

Berlin's monitoring network (BLUME-Messnetz) is presented in Figure 5- 2.

[28] 21. BImSchV - Twenty-First Ordinance Implementing the Federal Immission Control Act – Ordinance on the Limitation of Hydrocarbon Emissions during Refuelling of Motor Vehicles of 18 August 2014 (Federal Law Gazette [BGBl.] Part I p. 1453)'. Available at: www.bmub.bund.de/fileadmin/Daten_BMU/Download_PDF/Luft/bImschv_21_en_bf.pdf. Accessed 20 April 2017.

[29] Framework Directive 96/62/EC and two daughter directives were transposed to Germany through amendments to the Federal Immission Act and the 22nd Ordinance to the Act in autumn 2002 (Senate Department of Urban Development, 2005).

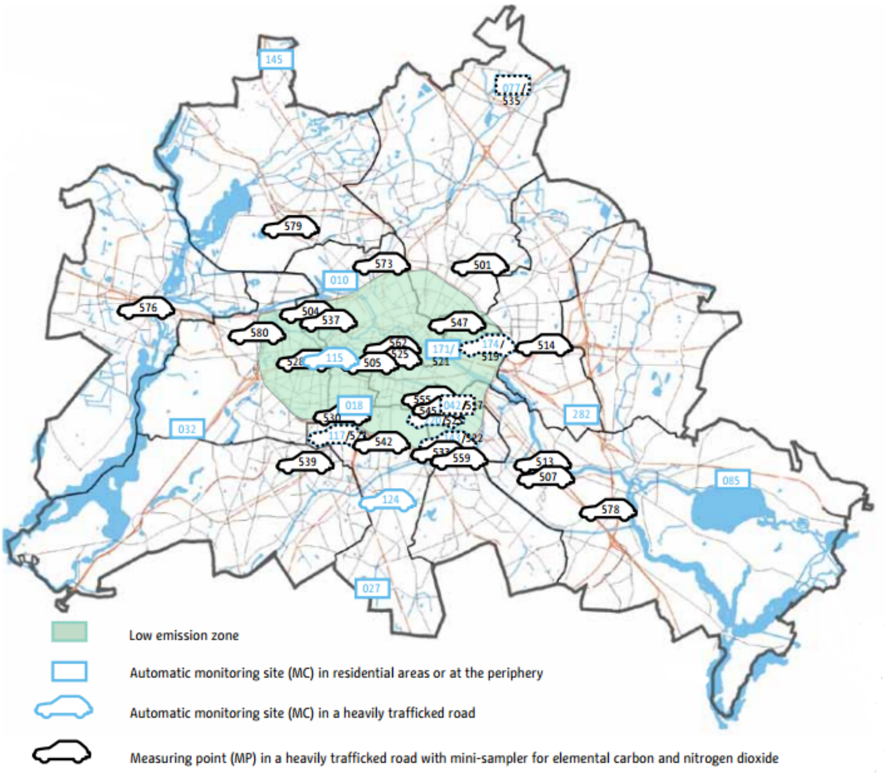

Figure 5- 2 Berlin air-quality monitoring-network 2010 (Senate Department for Urban Development and the Environment, 2014)

5.1.4 Information infrastructure and the dissemination of monitored air quality data

There are national and international legislative requirements for sharing air quality data. Internationally based on the Aarhus Convention, EU laws require all member states to establish an information infrastructure to make environmental data available to the public. In Germany, the German Federal Environment Agency (Umweltbundesamt, hereinafter UBA) collects the data both from their own network (mainly background concentration) and those operated by the federal states and publishes the information on their website.[30]

In Berlin, hourly readings, daily values (previous working day), monthly and annual reports of air quality data are available (in German) on the website[31] and are updated by the state's authority, the Senate Department for the Environment, Transport and Climate Protection. The data are presented in textual and/or table formats, without site information and spatial data. As in York, a new version with

[30] Accessible at: www.umweltbundesamt.de/en/data/current-concentrations-of-air-pollutants-in-germany, accessed: 24 July 2017

[31] www.berlin.de/senuvk/umwelt/luftqualitaet/de/messnetz/aktuelle_werte.shtml, accessed: 24 July 2017.

an interactive map and indicative air quality information has been made available.[32] Figure 5- 3 presents both of the old and new versions.

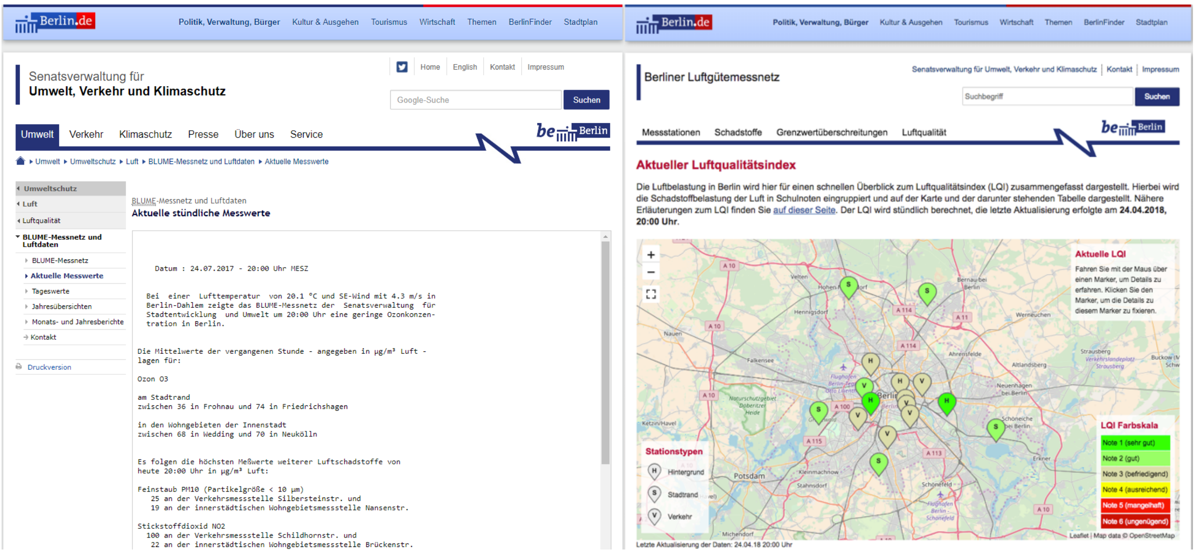

Figure 5- 3 Designated website for local air quality in Berlin, old (L) and new (R).

5.2 End-user stakeholders' participation and identification

In order to study the role of non-regulatory monitoring practice and the data generated in Berlin's air-quality monitoring and management, experienced end-user stakeholders were interviewed. As in the York study, the authorities responsible for air-quality monitoring and publishing air quality data were identified as important stakeholders and were therefore approached at an early stage for understanding the situation in Berlin. Also, even though the research focused on exploring the issue in Berlin, experts who have national or international experience were also invited, given the fact that Berlin is a well-known European capital city. At the same time, based on the experience gained in York and suggestions provided by the project partners, a list of other participants including environmental NGOs, environmental scientists and other interest groups was identified before the start of the fieldwork. In addition, snowballing was also employed for the purpose of obtaining in-depth knowledge about the topic and to maximise the number of participants. The theoretical saturation of the study was assessed by the range of information obtained during the process, but not the number of study participants.

[32] luftdaten.berlin.de/lqi, accessed on 24 April 2018.

The city code B was assigned to each of the interviewees in the coding process, i.e., Interviewee_B1 represents the first research participant in Berlin. The qualitative data were coded using Nvivo, guided by grounded theory.

5.3 Coding and the orienting themes

This section discusses the themes that emerged from the analysis in Berlin, which was informed by fourteen people between June and August 2016[33]. The interview data were coded in the light of the themes developed in York and new codes were noted when the topics were not covered by the orienting concepts. At the end of the coding process, new thematic concepts were established. The theme of *awareness and willingness* emerged via the analysis to be the core concept.

5.3.1 State and progress

Theme description

State and progress covers legislative requirements for air-quality monitoring and management, as well as the current situation with respect to the monitoring network and communication practice in Berlin. More specifically, it covers:

- policy development and progress of the air quality agenda,
- emission control policies (especially transportation),
- political systems and organisations with respect to air quality management,
- perceptions of the development of monitoring techniques, and
- use of generated air quality data and information provision.

This theme presents the state of air quality management in Berlin and provides the contextual background for the thematic analysis. It can be viewed as two subjects that are intrinsically linked: (1) first the state, which was established to refer to the current monitoring practice as well as legislative requirements and policy planning for air-quality monitoring and management; (2) second progress, captures the matters of time and change or development that were recognised by the participants, which

[33] The participants were speaking in a second language. Hence some of the English usage is inconsistent.

in turn was reflected in the current state through policy updates. This theme also illustrates how air-quality monitoring is employed in air quality policy-making.

As with many other cities in Europe, Berlin faces a problem with NO_2 emissions breaching the annual mean limit value of 40 $\mu g/m^3$ at roadside monitoring stations (Senate Department of Urban Development, 2005; Senate Department for Urban Development and the Environment, 2014). The phenomenon of continuous exceedance of the annual limit value and the difficulty in reducing concentration levels were well recognised by local informants (10/14). Although the majority of comments were related to transport policy, as traffic is the main emission source of NO_2 in cities, other factors were also noticed. For example, different stringencies of the air quality directive towards NO_2 hourly and annual average values (Interviewee_B2), the need for updated national regulations on vehicles (Iterviewee_B7), and the responsibility of car manufacturers who are important to the economy but lack interest in the issue (Interviewee_B13).

Interviewees also drew attention to particulate matter (PM). PM10, in particular, has been relatively well managed due to the implementation of a national labelling system (colourful stickers for vehicles meeting different Euro criteria), pushed by the Berlin government, and low emission zones (LEZ) in Berlin (Lutz, 2009; Holman et al., 2015). Positive improvements were recognised. For instance, '*on the PM situation we have improved*' (Interviewee_B7), '*it's a story of success*' (Interviewee_B9), and LEZ is '*a measure that works very well*' (Interviewee_B13). However, there are remaining circumstances that block further reductions in the pollution, which were highlighted by participants. A key issue is the complexity of source management. PM has a mixture of sources, e.g., traffic, industry, agriculture, wood burning, shipping, house heating (Interviewee_B1, B2, B6, B8, B12, B13), and different measures would be required to control each of the sources. Yet, as with NO_2 exceedance, there is a range of further hurdles, such as long-range transboundary emissions; contribution from a wider array of industries; and challenges of enforcement.

The monitoring of ambient urban air quality and the management of different emission sources is consequently a collective business, which involves a range of actors. It is necessary to have an in-depth examination of the end-user stakeholders of air-quality monitoring in the bigger issue of air quality management, for instance, the levels of *awareness and willingness* they have, the different *power* they possess and the different types of *responsibility* that they bear.

5.3.2 Awareness and willingness

Theme description

Awareness and willingness refers to public and political awareness of urban air pollution and willingness to address the issue. Specifically, it covers:

- knowledge of the availability of air quality information and how information is perceived amongst the end-user stakeholders,
- understanding adverse impacts of air pollution and willingness to take action to reduce the impacts,
- the extent to which air pollution is treated as a policy priority by authorities and political will to address the issue.

This theme captures the view of the public and of the city authority as in the York study. It encompasses the awareness of the pollution issue, solutions and whether and how end-user stakeholders are motivated to improve the situation.

5.3.2.1 Public awareness and willingness

When the participants were invited to reflect on whether air quality is an issue to the public, most of the informants who commented on the topic (8/14) observed that awareness raising is needed as the general public is not aware of air pollution, nor its impacts on health (Interviewee_B1, B2, B6, B7, B8, B11, B13). One interviewee made positive comments implying that there is a demand to acquire knowledge of air quality when it affects people's personal life (Interviewee_B12):

> *Of course, we receive a lot of questions regarding, for example, …, I have a child and I'm looking for appropriate kindergarten and one is located near a busy street, so would you say that it's good to take my child to this very place…*

Or when people want to raise a complaint:

> *…a lot of people are asking us: oh my neighbour burns wood and also there's black smoke from his chimney come into our garden and through our windows and we cannot open the windows anymore when he is heating, blah-blah-blah, and things like that.* [Interviewee_B12]

The respondents also noticed that in some cases, citizens may have an increased awareness of the issue for example, when someone has health problems (Interviewee_B7), has small children (Interviewee_B8), lives on a busy street (Interviewee_B8, B11), or when air pollution gets *'obvious'* or *'visible'* (Interviewee_B2, B8, B12). Despite these heightened perceptions, there was a view that in general, the public is not that concerned, or not alerted to the impacts of air pollution. It is an issue in the '*background'* (Interviewee_B7) and not relevant to the majority on a daily basis (Interviewee_B8). These perceptions agree with a 2015 European survey about air quality satisfaction in EU capital cities, in which 71% residents of Berlin were very or rather satisfied with the quality of air in Berlin (Eurostat, 2016). It ranked the eighth among the 28 European Union capital cities (ibid.). Indeed, as a new report indicated, air quality is not considered as the main environmental concern as 63% of German citizens nominated climate change as one (European Commission, 2017b). The participants' comments on public awareness of urban air pollution are tentatively measured on a spectrum of awareness ranging from '*very weak*' to '*very strong*' in order to demonstrate different views of the interviewees. In the analysis, public awareness was defined as '*very weak*' when air pollution was understood by the participant as not being part of public knowledge. Whilst it was evaluated as '*very strong*' if comments indicated that the public widely acknowledge the pollution issue and its health impacts. According to the empirical data, a '*very strong*' level of public awareness was not detected. The relative evaluation of public awareness based on the participants' interpretations is summarised in Figure 5- 4.

Very weak	Weak	Strong	Very strong
● Interviewee_B2 "I think that for most of the people other factors are more important" ● Interviewee_B6 "I think it's still not very well known in the public how large the, economic impacts of air pollution are, and also economic impacts on society but also on the individual..." ▲ Interviewee_B11 "there is no real consciousness that air quality is a big health issue" ▲ Interviewee_B13 "it's an additional point , …, an additional argument"	▲ Interviewee_B1 "…overall in Europe I think that people are not very aware of the issue of air quality" ▲ Interviewee_ B7 "I would say most people are not on a daily base but they are kind of aware of the issue a little bit in the background, …, but I don't think people are overly aware of the problem" ▲ Interviewee_B8 "if you ask, if the general public awareness is, they're recognising that we do have a problem with our air quality in Europe, then I would say so-and-so"	● Interviewee_B12 "we receive a lot of questions regarding, for example, …, I have a child and I'm looking for appropriate kindergarten and one is located near a busy street, so would you say that it's good to take my child to this very place…"	

● Government officials ▲ Environmental pressure groups ▲ Scientists

Figure 5- 4 The relative position of participant interpretations of public awareness of urban air quality issue

The participants also identified the barriers to the general public becoming aware of air pollution and its impacts. One of the main reasons reflected by the interviewees (Interviewee_B1, B2, B7, B8, B13) is that generally, air pollution is *invisible* to the citizens, as Interviewee_B1 noted:

> *…obviously there are days when it is (visible) and you can see it and things like that, but I don't think it's a visible enough problem that people necessarily make that association and make that link. …it's not something that's really in people's minds.*

Interviewee_B7 echoed this sentiment:

> *...people don't see it so they don't really believe in it…*

As such, people often neglect its impacts on health, as Interviewee_B2 commented:

> *The problem is that people don't die immediately, there are no dead humans on the road because of air pollution. It's a sort of this long-term, …, hidden threat.*

Another main barrier observed by the participants concerned communication and interpretation of air quality data. Interviewee_B2, B7, B8, B11 reflected that real-time and easily understood air quality information is missing for the city of Berlin. And where the information is available and accessible, i.e., on the website of Umweltbundesamt (UBA) at the federal level, the presented data are still '*too abstract*' for the public and is not tangible so that *'to bring them to change their behaviour it's even worse'* (Interviewee_B13). The issue of communication and interpretation of air quality data is not only limited by the way in which the authorities publicise such information, but also the media coverage, as the interviewee observed that the contrast with other sources of information – such as news broadcasts of other cities – diverts the public attention and affects how the issue is understood (Interviewee_B1, B8), for example:

> *because they have this contrast to the news that comes from places like China where, it's so visible and so bad that when you compare it here most of the time you kinda think: well, you know, it's fine. [Interviewee_B1]*

In addition, the informants also suggested underlying social and cultural reasons. The car culture and the NIMBY (not- in-my-backyard) syndrome in environmental topics, for example, add extra barriers to people understanding pollution and reaching for solutions:

> *…especially if you come to, to discuss the change in your mobility pattern then, …, it's the end of everything. [Interviewee_B8]*
>
> *So the mindset is like I have to be protected from that, but if there are any restrictions to protect me of that and I have then restrictions with my car behaviour then it's not good. [Interviewee_B11]*
>
> *…because if you have to implement some measures then it's nice if it is done, and my neighbour or what, wherever, but please not in my backyard. Maybe there's one big problem in Germany. [Interviewee_B12]*

In these instances, there is an implicit appreciation of the role of public responsibility in addressing urban air pollution and the importance of being aware of that. These aspects are detailed in the theme of responsibility.

In contrast to the resistance to change, the respondents also drew attention to the increasing number of cyclists (Interviewee_B2, B11, B13), which is regarded as a hint of social acceptance of changing transport usage:

> *…city public is ready to really make the change, …, it's unbelievable how much bicycle traffic is growing at the moment, and it's a real movement. [Interviewee_B13]*

Although there was no suggestion that this '*movement*' is motivated by the awareness of air pollution, it would reduce the emission from traffic, as Interviewee_B2 said:

> *Young people, you know, not really prone to have their own car, open for car sharing from multimodal mobility, biking is becoming fashionable. ..., I think it's more this cultural thing but it serves our environment purposes.*

Furthermore, according to the participants' experience, lacking interest (Interviewee_B2, B6, B13), lacking knowledge of air pollution and its impacts (Interviewee_B6, B11) were also barriers to public awareness.

5.3.2.2 Political awareness and willingness

In the majority of participant responses, there was a consensus that the government, in general, is aware of the existence of air pollution, and the concern is more about the political will to take regulatory action. Government is reluctant in particular with respect to any change in traffic policy due to the worry about public reaction:

> *Politicians don't really see air quality as something they can say it, because, some of the things are unpopular… politicians need to decide on this (the measures on how to change air quality) and they only want to do so if they feel they can do something green without being punished by the voters. [Interviewee_B7]*
>
> *… they are afraid to install unpopular things, … , a big problem or a big challenge is the public reaction, especially those people who want to be re-elected in two, three or four years. [Interviewee_B8]*
>
> *…it is a sticky topic in politics: you always have around forty million car drivers against you if you do anything in traffic policy which goes against the car. [Interviewee_B11]*

These perceptions reflected how different topics are considered in policy making and what influences political will, which is based on the balancing of different political interests and largely affected by the imperative to win the election (Schneider and Volkert, 1999). The awareness of voter's opinions, therefore, is vital when evaluating political measures for politicians seeking re-election. Thus, when voters or citizens are not well-informed about air pollution and its consequences, interviewees suggested that politicians tend to show limited interest and to fail to attend public engagement events. For example, in a conversation about effective air quality management and public engagement, Interviewee_B7 said:

> *…there also never have been campaigns ..., as the politicians, for example, (say) hey I want to do something positive for the city, I want to make, I don't know, less household heating, more solar heating on the roofs or something, I don't know, but it's never been a campaign.*

And Interviewee_B11:

> *Berlin is, policy-wise, ... is inexistent; I really do not understand that and how they can, ..., that they do not feel strange when they internationally try to sell Berlin as a success model. ... Strange, I mean there's a lot of citizen engagement around environmental topics and you (politicians) somehow are absent; that is strange.*

Yet, from the administrative point of view, the respondents suggested that the authorities are well aware of the complexity of air quality management. While most of the participants mentioned that urban traffic is the main source of emissions, which results in high concentrations of NO_2 in urban hotspots, the respondents also highlighted the complexities of emission sources, especially with respect to PM and the challenges of managing the emissions from agriculture (Interviewee_B6, B7, B8, B11) and international long-range transboundary sources (Interviewee_B2, B6, B12, B14).

The responses in this theme illustrate that there is a clear difference between public and political perspectives. Generally, the respondents felt that the public lacks awareness of air pollution and its impacts due to the perceived invisibility of this type of pollution and the lack of communication of air quality information. They also suggested that, there is a low level of public willingness to change behaviour, or that when such change does take place it is not a direct response to air pollution. In contrast, as air quality is an integral part of the environmental law, the authorities are aware of the issue, however, there is a lack of motivation to make an extra effort, especially due to the concern that the public will react against traffic or car restrictions. In addition, the challenges associated with controlling non-local emission sources were also recognised, especially with respect to the high level of PM.

5.3.3 Power and influence

Theme description

Power and influence refers to the capability of end-user stakeholders in terms of introducing any change in monitoring and managing local air quality activities. Specifically, it covers:

- possession of resources needed to establish air-quality monitoring practice and to implement control measures,
- legitimacy and political influence with respect to local air quality management,
- development and take up of new monitoring technologies, and
- public and policymakers' perceptions of non-regulatory monitoring and what the interests of end-user stakeholders are.

The Senate of Berlin operates a network in the city that monitors and reports on air quality data and reports to the Federal Environmental Agency (UBA). UBA collects and checks the data from Germany then sends reports to the European Environment Agency (Interviewee_B2, B7, B9). Although there is a collaboration between local, national and international levels, the management of the air-quality monitoring-network for Berlin is more of a local business:

> *…as far as air quality is concerned, …, the monitoring and the management in terms of these plans are mostly Länder business or communities… [Interviewee_B2]*

Therefore, the local authority shapes existing practices. Firstly, the primary function of air-quality monitoring and reporting is to serve legislative purposes. The location of monitoring stations and the technologies deployed must be consistent with the siting requirements of, and the reference methods specified by, the EU Air Quality Directive (Interviewee_B2, B6, B7, B9, B11, B12). While a low political willingness is also present (as detailed in the theme awareness and willingness), and public resources are limited (Interviewee_B2, B9), no additional monitoring or changes in routine monitoring are expected in the short term (Interviewee_B7, B12). As Interviewee_B1 remarked:

> *without the, basically, regulation there to say that they have to do this I think that's beyond their capacity to do*

That is to say, apart from the need to comply with the legislation, financial constraints limit the change to the monitoring of air quality, and affect the introduction of control measures, as one respondent remarked:

> *…that depends on the budget because you can always say, OK, now we have not enough money to pay all this construction work (for the cycling lane). And also the same is true for the renewal or improvement of public transport. ...,. these are really expensive compared, for example, to this low emission zone. [Interviewee_B12]*

Interviewee_B11 echoed this concern and analysed the economic situation from a historical point of view, noting that for the authority, '*everything you do in traffic starts being very expensive*' (Interviewee_B11). Hence the obstacles are actually political, lacking '*prioritisation*' of different interventions for instance. Interviewee_B8 sees this as a lack of effective collaboration within the administrative departments and an issue with the responsibility of the authority:

> *they have to argue with their people from the transport department and from the economic department and so-and-so. But ... there is no such a thing that you can say, well there would be a measure but it's too expensive, or it's too complicated, and so we don't take it, you have to take it…*

Other participants asserted that there is a need to improve national policies on PM concentrations (Interviewee_B7, B8, B6, B11, B13). One repeated topic was the emission of ammonia from agriculture, which increases the urban background level of PM concentrations but is currently not sufficiently regulated:

> *Very little regulation; so the emissions from agriculture basically are not monitored. ..., in Germany certainly, that is one big gap of regulation…but nowadays you won't be able to reduce PM pollution, for instance, without strongly reducing ammonia. So if you don't tackle ammonia emissions then you won't be able to solve that problem. [Interviewee_B6]*

Interviewees opined that the absence of regulation is due to the strong influence of the agricultural lobby (Interviewee_B11, B12). Another source of NOx at large scale is the international long-range transported particles from the other countries, which the city authority or even the federal government often lacks the power to manage (Interviewee_B2, B6, B11, B12, B14). Interviewee_B12 also expressed concerns about wood burning, which is a '*huge fraction of the particulate emissions*', but '*it's not so easy to have an inspection of all these individual fireplaces*'.

Yet, the participants expressed interest in developing or using new forms of a communication system for publishing and sharing air quality information, as well as possibilities for non-regulatory purposes, especially for the environmental NGOs and scientists (Interviewee_B1, B2, B7, B8, B10, B11, B13).

5.3.4 Responsibility

Theme description

Responsibility refers to the liability and duty of end-user stakeholders in monitoring and managing local air quality. It emerges from:

- possession of resources which are needed to monitor and/or improve air quality,
- distribution of impacts and accountability of the management organisation,
- scales of responsibility due to the impacts of air pollution (for example, local or national, personal).

Responsibility for air-quality monitoring and management is a heterogeneous concept, which involves multiple actors and their respective relations with air quality information in the formulation and enforcement of air quality control policies. It links to the theme of power and influence, extending the discussion on the possessor of power, and focuses on how responsibility should be distributed for effective air-quality monitoring and management. The theme refers to two main questions: which end-user stakeholders have the responsibility to reduce the emission, and what is the responsibility of an individual end-user stakeholder?

First, as shown in the theme of power and influence, a general reflection of the participants is that local governments are responsible for the monitoring and management of air quality. In the case of Berlin, the Senate has a legal duty to operate the monitoring network, publish air quality information to the public and take control measures in order to meet air quality limit values:

the competence or the responsibility to monitor is to a large extent on, on the Länder, the federal states, and on municipality level, but in most cases, or in almost all cases these are networks run by the federal states. [Interviewee_B2]

for matters about air quality in cities often this national level doesn't have a say, even though they're partly responsible it's a matter of the city or maximum the federal state to decide what is being done, also because the streets belong to them and it's not so much a jurisdiction of the state; so it's more the city. [Interviewee_B7]

Interviewee_B8 shares similar opinions and added that internal coordination and budget constraints of local government should not be the justification of ineffective management:

... There is no such a thing that you can say, 'well there would be a measure but it's too expensive, or it's too complicated, and so we don't take it'. You have to take it, you have to, you have to ensure air quality according to the legal requirement.

Yet, the participants noticed that there is a distribution of responsibility between different departments and different levels of governments (Interviewee_B2, B6, B7, B8, B12), an '*inter-departmental business*' (Interviewee_B2). However, the administration for public health is absent, '*the health departments ... they don't feel responsible at all for that problem*' (Interviewee_B13). Moreover, the implementation of control measures is affected by the capacities of each administration, for instance, the districts or boroughs of Berlin (Interviewee_B7, B11); and the scale of responsibilities and the power of different levels of governments, especially for the transboundary pollution of PM (Interviewee_B2, B6).

Industrial actors such as bus operators and car manufacturers are also important for abatement measures in Berlin. The Air Quality Plan of Berlin lists relevant administrations in charge of the implementation of control measures, including the specific department for air quality management (SenStadtUm), the federal government, other related Senate departments, districts, as well as public transport companies (Senate Department for Urban Development and the Environment, 2014). For emissions from public transport, although the number of electric buses is low (approx. 4/1320) (Senate Department for Urban Development and the Environment, 2014; Berlin Agency for Electromobility, 2015), public service buses are retrofitted with particulate filters and NO_2-control systems and the vehicle type approval includes real driving emission (RDE) tests (Interviewee_B2, B11). In contrast, the RDE test procedures for diesel passenger cars failed to be an effective one, for which the car manufacturers are responsible, as well as the national government:

> *The sticker system is a national regulation, so that's a German law, and it, and the government, the federal Ministry for, for Environment is now working on an extension of that sticker regulation, and the question is what sticker for which type of vehicles? Hopefully aren't necessarily for clean vehicles, what is clean here; so that was with low real driving emissions, real in both, not theoretically on a test stand with a bloody new European driving site, thank you very much. [Interviewee_B2]*

Also, the respondents paid attention to the responsibility of individuals. Interviewee_B6 remarked that individuals often lack awareness of their own responsibility in traffic management, which affects the implementation of reduction measures, makes enforcement a challenge and lowers expectations of improvement:

> *…so they tried, when they had these high PM concentrations, to convince people to leave their cars at home and it was not successful at all, at all, so nobody did. Many people were happy that there was less traffic so they used their car and they were faster with the car. So that more or less is a bit, not depressing but it keeps down the expectations that you would really change things strongly by increasing the information to individuals. [Interviewee_B6]*

Interviewee_11 noted:

> *… it's almost impossible to discuss it in a way that the own responsibility is clear and taken into account.*

And the reasons are lacking awareness and '*feeling restrictions as an individual*' (ibid.). Engaging and communicating with the public about knowledge on air quality, therefore, is a key step for behaviour changes and effective air quality management:

> *And you do not have the one handle or something; you really have to try from different perspectives, you have to bring it up all the time, you have to really point it out all the time, and it will never be done. [Interviewee_B11]*

That is also an important potential function of the portable air-quality sensors and communication tools (Interviewee_B1, B2, B6, B7, B8, B13). A question for such practice is, therefore, who should be responsible for the devices and interpreting the data? Interviewee_B13 observed that in some citizen science projects initiated by environmental NGOs in Europe, the citizens volunteered to manage the devices and even shared the cost:

> *…they felt responsible for a certain device, they made the maintenance, they even gave the money for it*

Some participants extended the discussion to the responsibility of providing the generated air quality information, as Interviewee_B12 commented: the data '*carry maybe some political message*' and without standardisation people '*maybe get some wrong impression*' due to the biased presentation and interpretation, so that for establishing and defining the approach public authorities should be responsible. Interviewee_B6 shared the same view that '*some minimum standards and so on*' are needed, and added that it is also a matter of the public trust in government, thus the answer may vary:

> *So Europeans would probably say government should establish some minimum standards and so on, but maybe that would be exactly the wrong, the wrong solution for Asian countries, for instance because people don't trust the government and they want to do their own… [Interviewee_B6]*

The views of participants suggest that alternative air-quality monitoring methods and the availability of new communication platforms could affect people's understanding of air quality issues. Therefore, technological innovation is an important theme for understanding the role of the new form of monitoring practice.

5.3.5 Technological innovation

Theme description

Technological innovation refers to the potential impact of sensing technology on managing local air quality, it involves:

- availability and features of non-regulatory air quality sensing technique,
- concerns about the challenges of the innovation,
- potential cost and benefits.

Technological innovation, in the context of air-quality monitoring and management, refers to portable sensing techniques and new forms of information-sharing systems, such as applications that run on a mobile device, such as a mobile phone.

In the majority of participant responses (8/14), there was a perception of the advantages of such additional monitoring and information sharing practice. For example, Interviewee_B7 noted that '*these monitoring devices can potentially make the monitoring network more dense (sic),*' as there is currently a limited number of monitoring stations in Berlin:

> *some areas don't have a measurement station, and there you don't have local data on air quality, there is simply no data. [Interviewee_B7]*

Interviewee_B2, B8 and B13 viewed portable devices a helpful tool for demonstrating the air quality issue to the public and construction companies. For instance:

> *It's a very smart way of showing to the public in particular, or to the construction companies … and saying, hey, I mean your machines are, are really polluting the air, and it's also an issue for your personnel,… it's also your task as an employer to ensure that no cancerogenous (sic) agents are inhaled by your personnel. [Interviewee_B2]*

Interviewee_B12 viewed the availability of additional information through a mobile application or personal sensor as an extra choice for particular citizens with specific health issues to make personal decisions:

> *Because you don't say you have to use these apps … because there are a lot of people, for example, suffering certain diseases and for them, it's maybe very important to know …, that would be one cornerstone for their decision-making, but of course not for everyone.*

Despite the advantages, the participants reflected that the new monitoring techniques and the generated data are mainly of research interest, for instance, they can be used in personal exposure studies or citizen science research, or assist environmental pressure groups in public engagement events, but cannot be used for legislative needs. The distinction is primarily caused by the concerns about the legitimacy of the monitoring method, data quality, and data communication to be used for compliance checking.

With respect to legitimacy, current monitoring methods are regulated by the EU Air Quality Directive, they are a 'prescribed' reference method (Interviewee_B2, B3, B4, B5, B9, B12). Any introduction of a new monitoring method has to be tested to prove that it is able to deliver the data with the same quality as the reference method, however, current portable monitoring techniques are not able to meet the testing requirements as official instruments (see Figure 5- 5):

> *This is far away from the equipment we use for ... official measurement, because they are operating on let's say a legal basis, because you have limit values, you get them by the European directive on air quality, and then you have to show that you are below these limit values, ..., for these measurements you really need measurement devices which are really tested and are really known that they are, for example, within a certain range of uncertainty for the measurements, and so usually these devices are very big, and so, therefore, these monitoring stations are really container and not only a smartphone. [Interviewee_B12]*

Figure 5- 5 The monitoring station (container) with equipment (top), and laboratory instruments (bottom) in Berlin

Moreover, the Air Quality Directive also requires continuous monitoring at specific locations in order to generate a valid daily and annual average, which is not feasible via portable monitoring (Interviewee_B2, B7, B12). Interviewee_B1 summarised that:

> *They are nowhere near the quality of basically (sic) standard monitoring techniques that are used in a regulatory sense.*

Being unable to generate data that are as reliable as those provided via statutory reference methods, therefore, is a crucial challenge for portable devices and the legitimacy of the data that they provide. Thus, these data cannot be used in official routine monitoring (Interviewee_B12), or as evidence in legal challenges (Interviewee_B7). There are therefore potential limits to the data generated from the devices being used as part of regulatory monitoring.

Additionally, the participants expressed concerns about the presentation and interpretation of generated air quality data from the voluntary monitoring even for non-regulatory purpose. First, interpretation is needed in order to understand the data. However, unlike government's routine monitoring method from which the authorities are able to publish the levels of concentration and provide explanations and health advice, there are no common specifications for commercial sensors. Technical specifications are decided by the manufactors. Interviewee_B8 said:

> *it always needs a lot of translation, what does it mean, what is a high number, what is a low number, what actually does happen if you breathe it in*

Besides, quality control is needed when the individual devices are used or combined in crowdsensing in order to produce relatively correct values. Nevertheless, who should take the duty to collect and check the data is still a question to answer, as Interviewee_B6 commented:

> *Whether it will really have a huge positive impact, (...), that really depends on how exactly the data that come out of these individual-based technologies are linked together, and who does that and how that is controlled, quality controlled and so on. [Interviewee_B6].*

Meanwhile, the participants from governments are more concerned about the consequences of poor air quality data. For example, Interviewee_B2 worries that without quality assurance, '*we may run into a problem of losing confidence and trust*'. Therefore, the experts suggested that a certification or standardisation of the small air-quality sensors needs to be established in order to use the data effectively (Interviewee_B2, B6, B9, B12).

Given the current technical performance, although feeding additional air quality information from portable devices into existing routine monitoring network is inappropriate for a regulatory purpose, new forms of monitoring practice may provide potentially beneficial supplementary information. In the first place, the participants identified that it benefits scientific research, for example, modelling improvement and personal exposure studies (Interviewee_B2, B7, B9, B10, B12). It also can be used in citizen science and environmental education as an indicative tool for awareness raising for the public (Interviewee_B1, B2, B7, B8, B13). The respondents also noticed the positive effects on regulation. For instance, Interviewee_B6 identified the potential for the younger generation to inaugurate policy changes:

> *If you go to a sixteen-year-old and show him this flashy instrument and then you have a very different access than if he hears that the government does something, ..., it's much easier to get people interested in this issue if they can do something themselves.*

Interviewee_B7 noted the influence on motivating politicians:

> *…more people are measuring, there is also the higher chance for the politician to be motivated to try it, and so this bigger group of measuring people also creates more incentives for the politicians to actually do something*

Additionally, these data could provide a supplementary method to keep the government accountable, adding transparency (Interviewee_B6, B7) and enabling the public to make a 'statement' in city development (Interviewee_B10).

5.4 Linking the grounded theory themes

This section brings together the orienting themes and presents the relations between them. It also includes the updates on the themes' description, as the meanings were adapted for the Berlin context. The identified themes are 1) awareness and willingness, 2) state and progress, 3) power and influence, 4) responsibility, and 5) technological innovation. The relations of the themes can be found in Figure 5- 6.

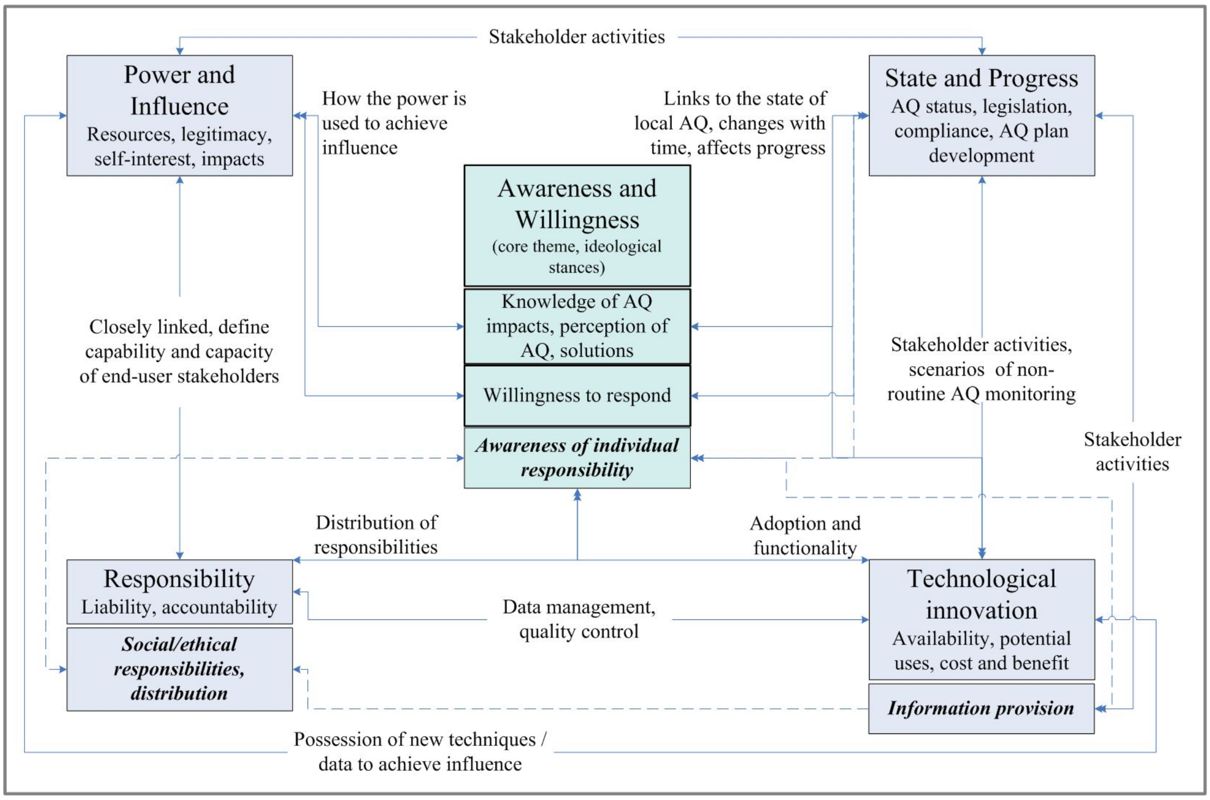

Figure 5- 6 Relations between the developed grounded theory themes in Berlin, details added in italic

On State and Progress, the interviewees suggested that despite the success in vehicle and transport management, Berlin still faces challenges in reducing exhaust emissions of diesel vehicles and meeting PM10 and NO_2 standards. They also highlighted the impacts of transported airborne pollutants and the fallout of dieselgate on urban air pollution management. The need to control non-local emission sources to reach PM reduction targets requires national coordination and collaboration. The improvement of vehicle technologies and RDE test procedures need national efforts at least (Power). Yet, monitoring and management of urban air quality are administrative duties of the citizens are not aware of the problem or their own responsibility.

The theme of awareness and willingness was prioritised and identified as the core concept as a result of the analysis. It connects all other themes and reveals that the fundamental issue regarding the use of air-quality monitoring is wider social-political considerations for which the monitoring is applied. Awareness and willingness underpin the challenges in Berlin's air-quality monitoring and management. The theme reveals how the issue is perceived and what affects people's understanding of air pollution. Awareness is dependent on the perspective of the participant and the state (theme state and progress) within which the respondent evaluates the impact of air pollution on their daily life (end-user stakeholders' interest), the possible benefits and costs of taking actions in monitoring or behaviour change. The responses also illustrated different levels of willingness, which in turn affect progress in air-quality monitoring practice and emission control measures. In the previous York study, the respondents were focused more on the awareness of pollution issue and its impacts, yet, participants in the Berlin case pointed out that personal awareness of responsibility is also an important aspect. Consequently, the awareness of individual responsibility was incorporated into the theme description for responsibility.

In the theme of power and influence, the end-user stakeholders with power were considered to be able to influence state and progress, however, they may not have the awareness or willingness to do so. As in York, the politicians in the case of Berlin are end-user stakeholders of air-quality monitoring and data. But according to the responses, they are less active in environmental matters compared to those in York, and they are viewed as being resistant to changes due to limited material resources (money and personnel) and concern about public reaction to restrictive transport policy.

Responses in this study showed that responsibility for air-quality monitoring and management is a complex concept which consists of different types of responsibility that connect with other themes in different ways. Responsibility was defined by the legal duty of the authority and ethical obligations of the society. For the authorities, the consensus of the participants was that governments have the knowledge (awareness) of the issue, as well as the legal competence (power) to carry out (influence) the monitoring and management of urban air quality. However, there is no responsibility for the specific administration, i.e., air quality department, to ensure other departments are aware of the issue and support implementation. There is also no legal scope to carry out additional non-regulatory monitoring and communication activities. Meanwhile, there was a perception among the interviewees that even though the citizens of Berlin show a high interest in cycling culture, the public, in general, is not aware of urban air pollution. Thus, although the general public is the ultimate user of air quality information and beneficiary of air quality improvement, the interviewees suggested that citizens are not aware of their responsibilities and often have no voice and little influence on policymaking. Environmental pressure groups, especially environmental NGOs, seek to provide a voice to government and to engage the public to raise the awareness in order to build the public and political will to address pollution issue. However, weak public interest and poor availability of air quality information are considered by the interviewees to constrain ENGOs' influence.

Technological innovation was viewed by the participants as practical apparatus that could increase the opportunity of raising awareness and willingness with respect to air-quality monitoring and management. The participants see the potential of a range of activities for non-regulatory uses, for example, research, public engagement and environmental education to promote behaviour change. The availability of user-friendly monitoring devices and new forms of information provision, such as smartphone applications, are useful for environmental NGOs in particular, to increase their voice in the development of air quality plans (progress). Yet, the respondents had concerns about the use of these technologies in routine monitoring, mainly due to the legitimacy of techniques, the data quality and data management. A matter of responsibility in such issues was, therefore, raised, as the participants recognised that the presentation and interpretation of data could affect the understanding of air pollution in the city.

Overall, the orienting themes developed from the York study are largely applicable to the Berlin case. The ways in which the themes connect is similar to York. Yet, some issues were raised, although largely insignificant ones of what the themes covers, which arose from the accumulation of coding data collected in two cities. Specifically, these are issues covered by the theme of Awareness and Willingness, Responsibility and Technological Innovation.

According to the respondents, the citizens, private car users in particular, are also responsible for air quality improvement. For example, road transport is a significant source of local air pollution. Yet, it is the right of citizens to use their cars and there are no legal requirements in Berlin restricting driving habits. Similarly, how to use public transport and whether to participate in environmental actions are all decisions of the public. However, the public may not care or be aware that they may have a responsibility to reduce exhaust emissions. Following the analysis and coding of the Berlin data, this issue of social/ethical responsibility was added to the theme of Responsibility, and the self-awareness of personal responsibility was included in the concept of Awareness and Willingness.

The interviewees also indicated that the availability of new monitoring techniques may introduce more opportunities to raise public awareness of local air quality issues. In comparison with the established official monitoring practice, low-cost sensors are able to provide instant results to the users. Yet, there were concerns (as in the York case) regarding the quality control and data management of such practice. First, the accuracy of measurements is still a challenge for small, portable devices. Furthermore, the interpretation of atmospheric measurements may affect public perception and understanding of air quality management. The information provision as a function provided by the emerging monitoring practice is an advantage of new technologies. Meanwhile, how the generated data from new monitoring activities is managed is associated with the distribution of responsibilities. Hence, the subject of information provision was added to the theme of technological innovation, while the matter of how responsibilities are distributed was considered in the theme of Responsibility.

The updated theme descriptions are detailed in the following Table 5- 1.

Table 5- 1 Developed themes with description and modification (Berlin)

Theme	Summary for York analysis	Summary for Berlin analysis
State and progress	• Policy development and progress of the air quality agenda • Emission control policies (especially transportation) • Political system and organisations with respect to the monitoring and management of air quality • Perceptions of the development of monitoring techniques • Use of generated air quality data and information provision	
Awareness and willingness	• Knowledge of the availability of air quality information channel and how that information is perceived • Understanding of the adverse impacts of air pollution and willingness to change the behaviour • Policy priority and political will to tackle air pollution	In addition: • Awareness of self-responsibility
Power and influence	• Possession of resources which are needed to establish air-quality monitoring practice and implement control measures • Legitimacy and political influence with respect to local air quality management • Development and challenges in terms of taking-up new monitoring technologies • How the impacts of non-regulatory monitoring are perceived and what interests do end-user stakeholders have	
Responsibility	• Possession of resources which are needed to monitor and/or improve air quality • Distribution of impacts and accountability of the management organisation • Scales of responsibility due to the impacts of air pollution (for example, local or national, personal)	In addition: • Types of responsibility (legal or ethical) • Distribution of responsibility for data management
Technological innovation	• Availability and features of non-regulatory air quality sensing technique • Concerns about the challenges of the innovation • Potential functions, cost and benefits	In addition: • Forms of information provision

5.5 Chapter conclusion

This chapter presented the empirical findings of Berlin and explored the role of air-quality monitoring and issues in air quality management. The first part of the chapter, section 5.1 and 5.2 provided the background of Berlin and the participation of end-user stakeholders within the research. The participants were the direct users of air quality data, regardless of the techniques of monitoring.

A key analytical development emerged from this chapter once the Berlin data has been coded. The researcher reviewed the Berlin and York cases together in order to dertermine if there were any commonalities or differences across the two cases that could or should inform the use and content of the themes and subsequent coding practice. Commonalities across the two European cases were identified. The findings suggest that the general themes: 1) State and Progress; 2) Awareness and Willingness; 3) Power and Influence; 4) Responsibility; and 5) Technological innovation, were also applicable to Berlin.

Nevertheless, the sub-topics and the extent of each theme were modified. For example, in the theme of State and Progress, for both of the cities, the participants pointed out that the management of road traffic and vehicle emissions, diesel cars, in particular, is key to air quality management. The responses in Berlin also pointed out issues with respect to PM management, which is a key challenge for Berlin. Awareness of self-responsibility which involves both legal and moral viewpoints emerged as an important aspect of the themes of awareness and willingness, and responsibility. Therefore, the description of themes was modified. The relationship between the themes is summarised in section 5.4, in which, the theme of Awareness and Willingness was again determined as the central core theme. It not only links the other concepts but also reveals the fundamental factors that affect air-quality monitoring and management in cities.

The following chapter evaluates air-quality monitoring and management issues in Seoul, South Korea. The analysis draws particular attention to the core concept, Awareness and Willingness, as well as the Technological innovation. They were identified due to the prominence identified by the participants in the two case studies (core theme), and the topic of the research project. Reviews of the common issues using the thematic framework, in the light of the end-user stakeholder-centric understanding are presented at the end of this chapter.

6.0 Introduction

This chapter presents the findings of the Seoul case study, which focuses upon the role of air-quality monitoring and issues with respect to local air quality management. The themes that emerged from the qualitative data of York (Chapter Four) and Berlin (Chapter Five) were used to organise the analysis for this case study.

Section 6.1 outlines the city profile of Seoul as well as the institutional and legal context for air-quality monitoring and management in the city. Section 6.2 identifies the end-user stakeholders and introduces the interviewees as well as their involvement with respect to Seoul's air quality issues. Section 6.3 applies the themes from York and Berlin to guide the analysis of the qualitative data gathered in Seoul. The results show that the themes generated from previous case studies are pertinent to Seoul. Yet certain concepts are distinct in this urban context, for example, public awareness in the theme of awareness and willingness, and the significance of international collaboration for addressing transboundary pollution in the theme of power and influence. Section 6.4 relates the developed themes and summarises the commonalities across the three cities, finally, section 6.5 summarises the conclusions of the analysis for Seoul.

6.1 Seoul and its air quality policies

6.1.1 Seoul: a mega city in Asia

With over 10 million residents, Seoul Special Metropolitan City is the capital and the largest metropolis of the Republic of Korea (Seoul Metropolitan Government, 2013a, Statistics Korea, 2016). It forms the heart of the Seoul Metropolitan Area (SMA)[34], which consists of the Seoul Metropolitan City, the Incheon Metropolitan City, and Gyeonggi province, accounting for almost half (49.5 percent) of the total population of South Korea (OECD, 2005; Statistics Korea, 2016).

[34] Also referred as the Seoul Metropolitan Region (Ministry of Environment, 2015c), the Seoul Capital Area or the Capital region (OECD, 2006), and Sudogwon (Kim, 2015) in documents.

Seoul has the highest population density of South Korean cities and of OECD capitals (Kown et al., 2016; Statistics Korea, 2016; OECD, 2017). It sits in the middle of the Korean peninsula, is near the west coast and is surrounded by mountains. The Han River (Hangang) flows across the city from east to west and divides the city into two parts (Gangnam, 'south of the river' and Gangbuk, 'north of the river') (Seoul Metropolitan Government, 2013a; Kown et al., 2016). The mountainous topography and the high population density exacerbate the challenge of managing air quality in the city due to the complex terrain, dense urban development as well as high volume of car ownership (Mage et al., 1996; Britter and Hanna, 2003; Lee et al., 2008).

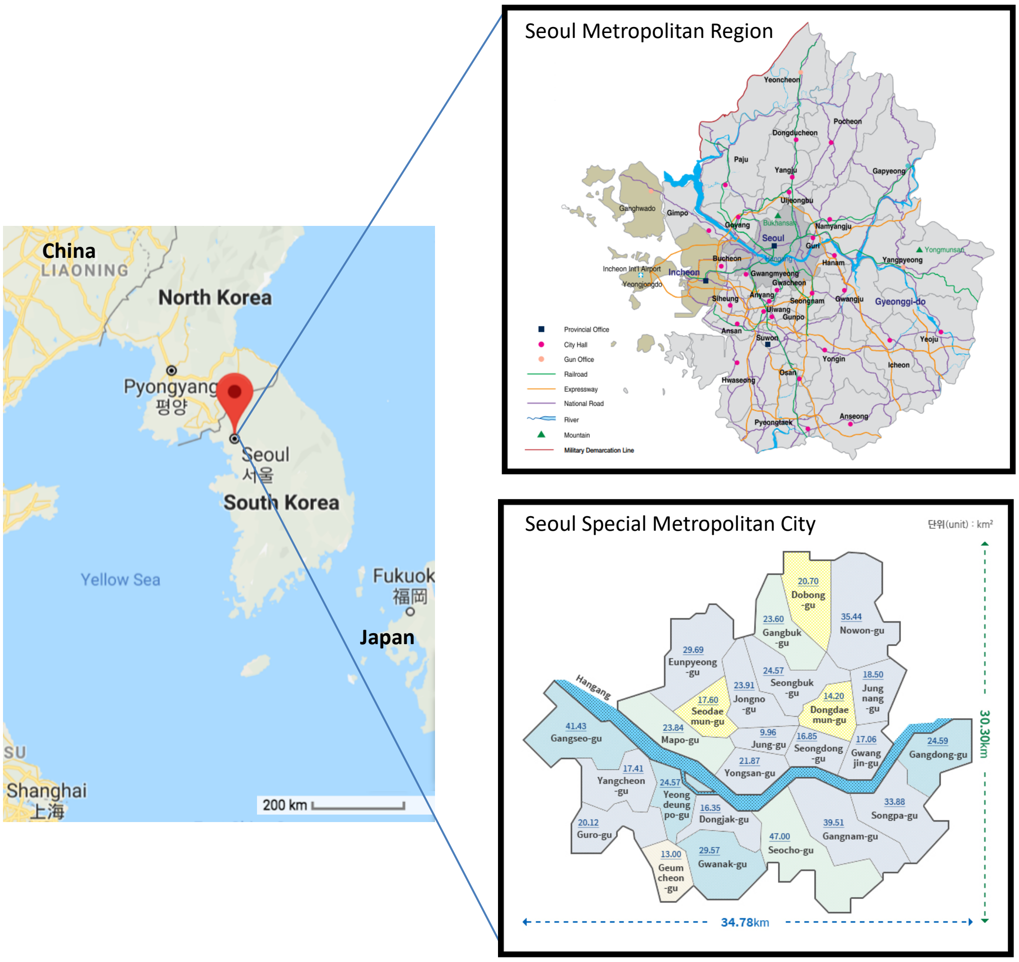

Figure 6- 1 Location of the study city: Seoul, South Korea (modified based on Google (2019), left; Kown et al. (2016), top right; Seoul Metropolitan Government (2013a), bottom right)[35]

[35] The presentation of the map does not imply any judgement on the legal status of or sovereignty over any territory in the area.

As for air quality, South Korea has for decades implemented management efforts to address air pollution and Seoul has been measuring air pollution since 1973 (Dong and Lee, 2017) , which has led to some positive results in improving national standards and strengthening regulations. For example, the concentrations of SO_2 and CO have significantly decreased since the 1990s (Ministry of Environment, 2015c). However, the entire country is exceeding the WHO guideline for PM 2.5 concentrations of 10 $\mu g/m^3$, and air pollution levels in dense metropolises are particularly high (OECD, 2017). The management of PM and NO_2 concentrations remain challenging especially for the metropolitan city of Seoul (National Institute of Environmental Research, 2017). The following figures show the changes of the monitored NO_2 and PM concentrations in seven metropolitan cities, of which Seoul has relatively high average concentrations.

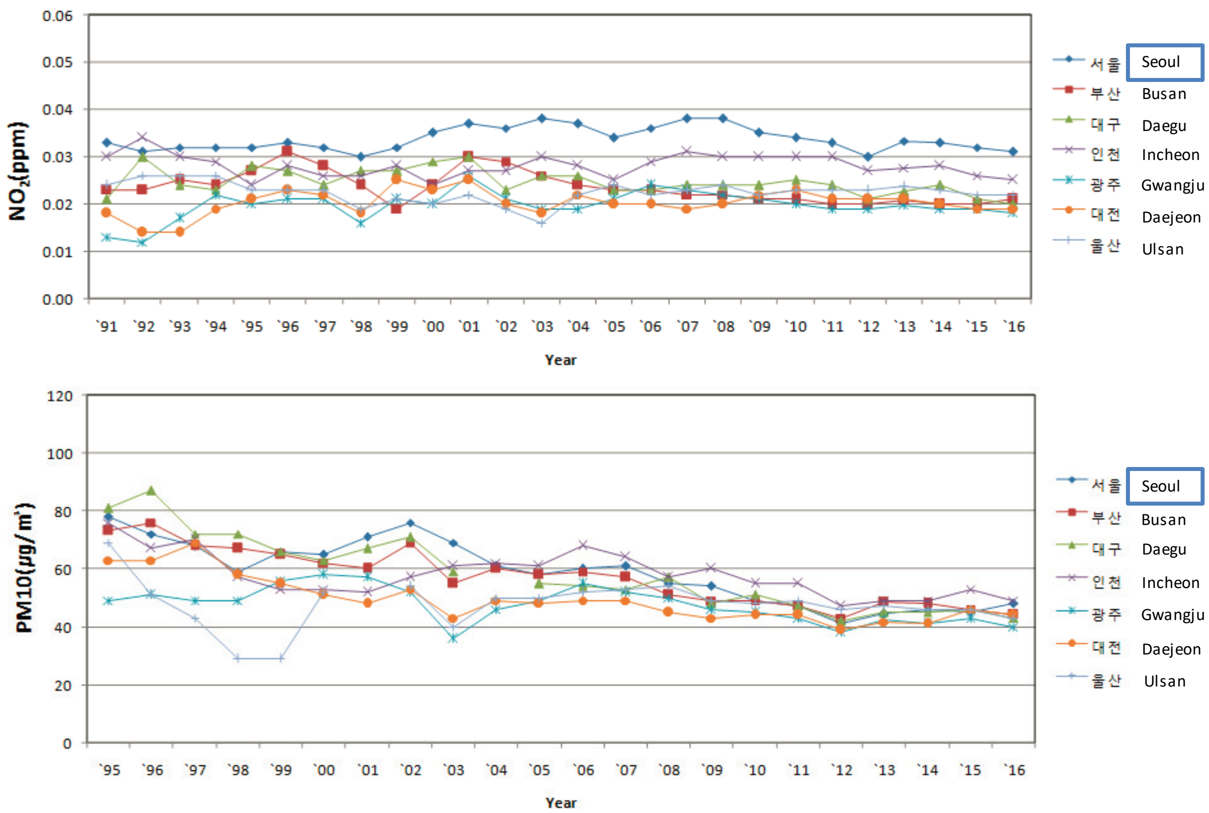

Figure 6- 2 Changes of annual average concentrations of NO_2 (ppm) and PM 10 ($\mu g/m^3$) in metropolitan cities of South Korea (National Institute of Environmental Research, 2017)

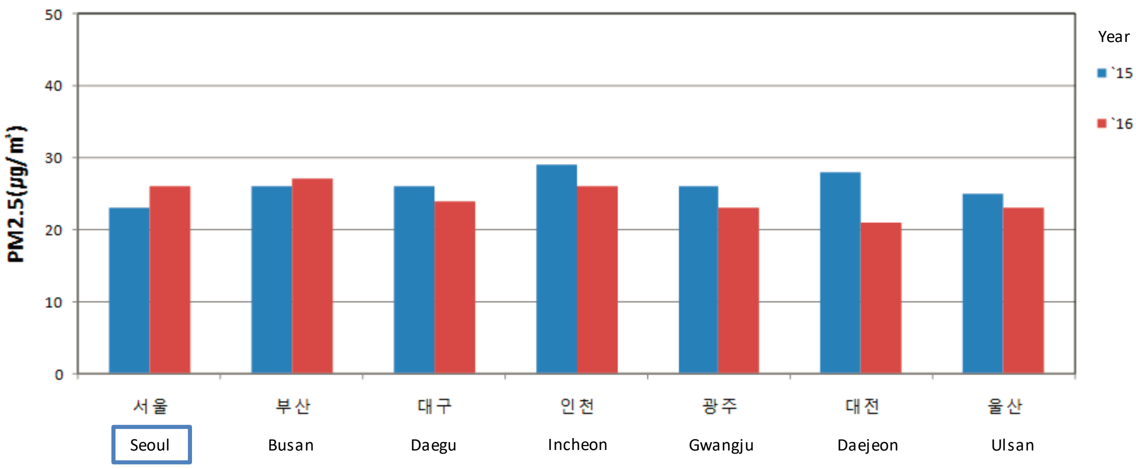

Figure 6- 3 Annual average concentrations of PM 2.5 (μg/m^3) in metropolitan cities of South Korea in 2015 and 2016 (National Institute of Environmental Research, 2017)

6.1.2 Legislative background

The Ministry of Environment (MoE) is the primary national administration responsible for coordinating and developing air quality policies in the Republic of Korea. It was upgraded to be a Ministry in its own right in 1990, prior to which it was a subsidiary of the Ministry of Health and Society (Ministry of Environment, n.d.).

The basic legislation is the Clean Air Conservation Act (CAC) which was passed as part of the Framework Act on Environmental Policy in 1990 (Seoul Metropolitan Government, 2015d). The CAC regulates pollutant emission limits and determines ambient air quality standards. The Act has undergone several revisions since it was enacted. In its 1995 revision, the municipal authorities and provincial governors were allowed to develop and implement local policies for air quality improvement in their areas of jurisdiction (Seoul Metropolitan Government, 2015d; OECD, 2017). As such, although South Korea has a centralised system, it has a great level of local autonomy regarding environmental issues and the provincial and local governments have the power to set local air quality standards and share policy implementation responsibilities. In line with the Act, the Seoul Metropolitan Government (SMG), which has a unique legal status that is under the direct control of the Prime Minister, promulgated the Seoul Local Air Environment Standard in 1998 and established an air quality management division (Seoul Metropolitan Government, 2015d). The ambient air quality standards of Seoul were stricter compared to the national ones at that time (ibid.).

Although a wide range of policies on industrial emission and fuel use have been implemented in accordance with the Clean Air Conservation Act, there was no significant improvement in air pollution, particularly relating to vehicle emissions in the capital area. Therefore, in 2003 the national government legislated a Special Act on the Improvement of the Air & Environment in the Seoul Metropolitan Area (the 'Special Act on the Air') (enforced in 2005) (Ministry of Environment, 2015c). And a new Metropolitan (Sudokwon) Air Quality Management Office under the MoE was established in order to implement stricter policies to tackle air pollution in the SMA (Seoul, Incheon and 24 other cities in Gyeonggi Province) (OECD, 2006a). According to the Act, a framework plan and action plan would be carried out in the region. The first ten-year air quality plan, 1st Seoul Metropolitan Air Quality Control Master Plan (2005-2014), was introduced in 2006 and sought to reduce PM10 and NO_2 emissions by half from 2001 to 2014 to reach the same levels as Tokyo (PM10 40 μg/m3) and Paris (NO_2 22 ppb), respectively. The second Master Plan (2015-2024) was formulated in 2013, aiming at air quality improvement to reduce human health risks. The list of pollutants was extended by adding PM2.5 and ground level ozone (O_3) to that of the first plan, i.e., PM10, NOx, SOx, and VOCs and target values for PM2.5, PM10, NO_2 were set at 20 $\mu g/m^3$, 30 $\mu g/m^3$, 21 ppb, respectively (Ministry of Environment, 2015c; Don and Yeo, 2017). The government made PM issue a national priority and announced a KRW 5 trillion budget (USD 4.4 billion) in 2016 (OECD, 2017).

Locally, the SMG has implemented various initiatives to improve air quality and prioritised the issue in its policy-making. For example, the government has tightened vehicle emission standards with US standards for petrol and EU standards for diesel, converted city buses from diesel to CNG (Compressed Natural Gas) buses, implemented a low-emission programme to address emissions from old diesel vehicles, promoted eco-friendly boilers with low NOx burners, and employed dust-absorbing vehicles for street cleaning (Seoul Metropolitan Government, 2013b; Seoul Metropolitan Government, 2014; OECD, 2017). In the recent 'Four-Year Plan for Seoul', in which the government aims to make Seoul a 'Safe, Warm, Dreaming, and Breathing City', the authority released an ambitious goal of reducing the concentration of PM2.5 by 20% by 2018 based on the level of 2013, from 25 $\mu g/m^3$ to 20 $\mu g/m^3$, and launched a ‘Reduce Fine Particle Pollution by 20 Percent’ project in 2014 (Seoul Metropolitan Government, 2017a; Seoul Metropolitan Government, 2017c).

Internationally, the Environment Ministers of South Korea, Japan and China have been discussing environmental issues in the region annually since 1999, at the Tripartite Environment Ministers Meeting (TEMM) (TEMM, 2016). Following a proposal made at the 15th TEMM in 2013, the three countries agreed to organise a Tripartite Policy Dialogue on Air Pollution annually to cope with the increasing concerns over air pollution (Ministry of Environment, 2015a).

The SMG is also active in international cooperation for air quality improvement. The city has hosted seminars on Improving Air Quality in Northeast Asia since 2010, which expanded into the ‘Seoul International Forum on Air Quality Improvement’ in 2014 (Seoul Metropolitan Government, 2015b). The same year the first Tripartite Policy Dialogue on Air Pollution was held (Ministry of Environment, 2015a). At the forum, Seoul and 12 other cities of China, Japan, South Korea and Mongolia agreed on collaboration and made reduction targets at municipal levels (Seoul Metropolitan Government, 2015b).

6.1.3 Air-quality monitoring in Seoul

Korea Environmental Corporation (K-eco), a subsidiary of the MOE operates the national air-quality monitoring-network and monitoring data (Ministry of Environment, 2015b; K-eco, 2017). At the end of 2016, K-eco was managing a total of 120 stations including seven types of monitoring systems, i.e., the national background, suburban air, stations for photochemicals, acid rain, air-toxic, earth climate, as well as PM2.5 (K-eco, 2017).

At the municipal level, the SMG started monitoring air quality in the 1970s and the original four stations have been extended into a comprehensive monitoring system consisting of 46 stationary stations and 6 mobile monitoring vans in total (Seoul Metropolitan Government, 2015a; Dong and Lee, 2017). The stations include five types of monitoring networks including the City Air-quality monitoring System (25 stations, 1 for each district) and Roadside Air-quality monitoring (15 stations). There are also special monitoring sites for photochemical pollutants, acid decomposition monitoring stations for measuring PH levels of acid rain, as well as a heavy-metal monitoring system. (Seoul Metropolitan Government, 2015a; Dong and Lee, 2017). For ambient urban air-quality monitoring, the Seoul Research Institute of

Public Health and Environment under the SMG operates the 25 city and 15 roadside air-quality monitoring stations (Seoul Metropolitan Government, 2015a). The following figure (Figure 6- 4) presents the air-quality monitoring stations of Seoul.

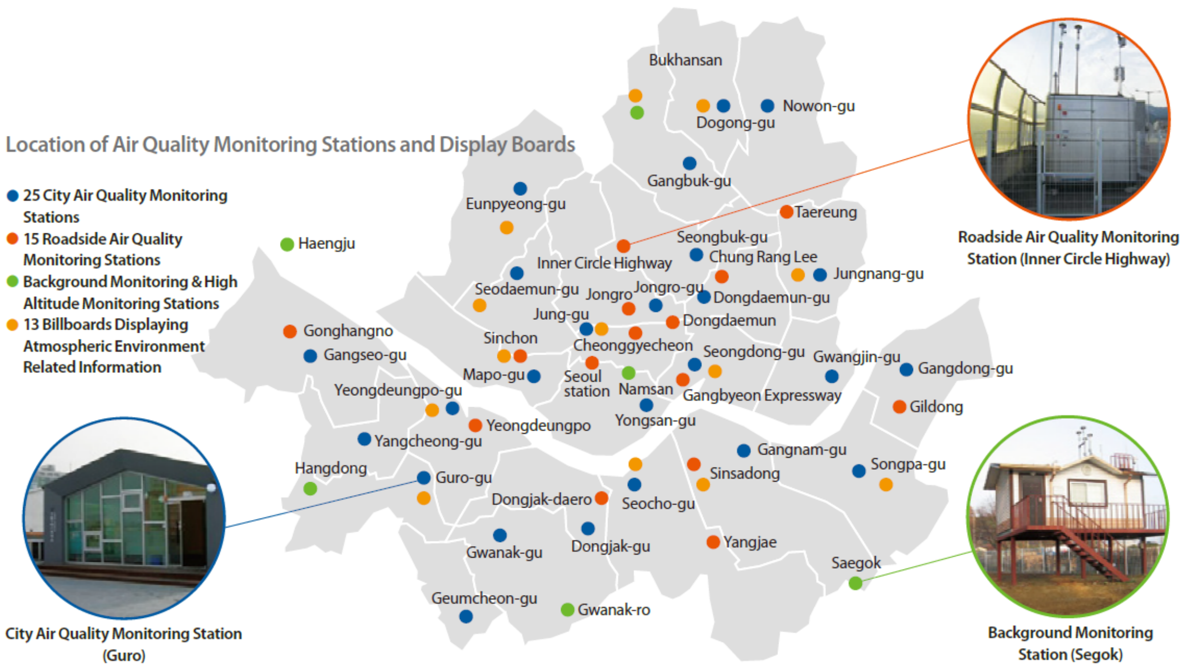

Figure 6- 4 Air-quality monitoring stations in Seoul (Seoul Metropolitan Government, 2015a)

6.1.4 Information infrastructure

Public access to environmental information is protected by law in South Korea. In accordance with the 1996 Act on Access to Public Information, most of the information held by the authorities including air quality is accessible to the public on request, unless it is considered confidential or related to national security (OECD, 2006a).

An information infrastructure has been established to better inform the public about air quality due to increasing concerns. At the national level, the MoE and its affiliated agency, the National Institute of Environmental Research (NIER) publish policies and reports with respect to air pollution control regularly on their websites[36]. As of April 2002, the MoE has opened the real-time air quality in 16 stations near the World Cup Stadium and more information across the country is open to the public at

[36] MoE: www.nier.go.kr (Korean), www.nier.go.kr/eric/portal/eng (English), and NIER: www.me.go.kr (Korean), www.eng.me.go.kr (English), respectively.

the end of 2005 (KECO, n.d.). Administratively, on behalf of the MoE, K-eco collects monitored air quality data from national stations, receives urban air quality data from local authorities and processes the air quality data from 320 stations (including three out of seven types of monitoring systems, i.e., national background, suburban, and urban streets) through the National Ambient Air Monitoring Information System (NAMIS) (K-eco, 2017). The real-time statistics, trends of past readings, forecasts as well as warnings and related information are open to the public on the designated national air quality information website, Air Korea.[37] Although more details are provided in Korean, for example, the annual air quality report, English information involving the real-time statistics and warnings is available. The annual statistics and general environmental data are published by the MoE in the Environmental Statistical Year Book and are made available to the public on the Environmental Statistics Portal System[38] (Ministry of Environment, 2013).

As for Seoul, SMG provides air quality measurements to the public through various channels. The Seoul Public Health and Environment Research Institute under the local government manages the routine ambient air-quality monitoring of Seoul and processes the generated data (Seoul Metropolitan Government, 2017d). Real-time information of atmospheric pollutants including ozone and fine particles (PM2.5 and PM10), projections and warning information are published on the specific Air Quality Information website for Seoul[39]. The same indications are also available in multiple languages on the government's webpage[40]. In addition, Seoul has established a warning system in which forecast and alert notices are not only available on the website but are also sent to the public through text messages by mobile operators and published on electronic boards on main roads, radio and television (Seoul Metropolitan Government, 2015a). The government also has direct communication with schools and care centres (ibid.). As of September 2017, the notice time of warning message when PM and ozone levels exceed the air quality standards has shortened to 7 minutes from the average of 30 minutes by establishing the 'Automatic Air Pollution Alert System' (Seoul Metropolitan Government, 2017b). In

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[37] airkorea.or.kr (Korean), airkorea.or.kr/eng (English)
[38] stat.me.go.kr/nesis.
[39] cleanair.seoul.go.kr (Korean)
[40] The air quality information is also available in English, Simplified Chinese, Traditional Chinese, Spanish and French.

the following, Figure 6- 5and Figure 6- 6 illustrate the media channels for disseminating air quality information in Seoul.

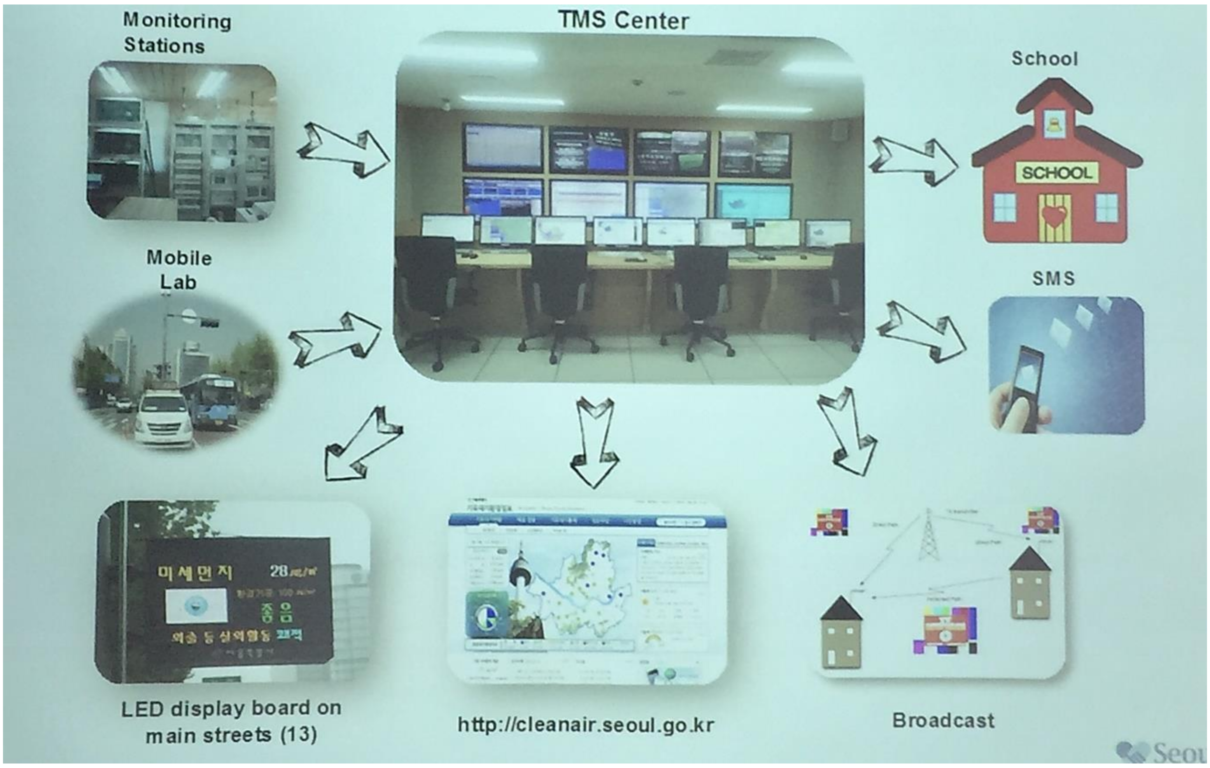

Figure 6- 5 Air-quality monitoring and dissemination channels in Seoul, presented by Seoul Metropolitan Government

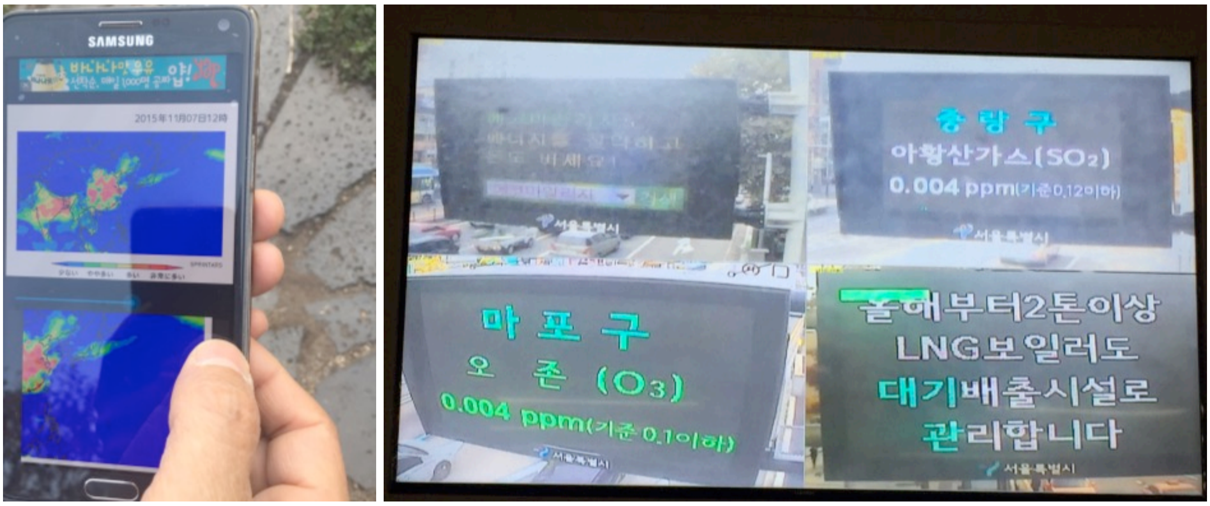

Figure 6- 6 Real-time air quality information inquiry via mobile

In addition, the Seoul Tower at Namsan (Mt.), a landmark of the city, has been employed as an indicator since 2011 (Dong and Lee, 2017). It is illuminated in blue when air quality is considered to be good. This indicator was based on PM10 originally and switched to PM2.5 from 2015 (Seoul Metropolitan Government, 2012; Dong and Lee, 2017). The colour indicators are presented in Figure 6- 7.

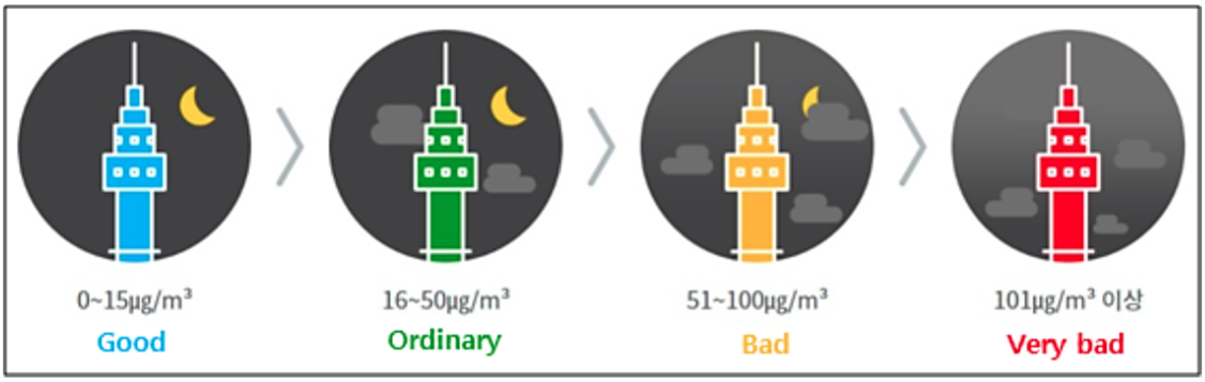

Figure 6- 7 The colour of the Seoul Tower as an indication of air quality, based on the level of PM2.5 (Dong and Lee, 2017)

6.2 End-user stakeholders' participation and identification

Air-quality monitoring in Seoul is controlled by government affiliates; consequently, these organisations were identified as the key end-user stakeholders. In addition, as civil participation with respect to environmental issues is very active in Korea, atmospheric scientists and environmental pressure groups were also identified as important stakeholders. The project partner from Seoul National University helped to arrange contacts and set up interviews with a majority of the key experts (nine out of ten) drawn from these two broad categories of stakeholders.

The city code S was assigned to each of the interviewees in the coding process, i.e., Interviewee_S1 represents the first informant who was approached for the Seoul study. The qualitative data were analysed applying the same method as in the other two cities, which were coded using Nvivo, and guided by grounded theory.

6.3 Coding and the orienting themes

This section discusses the thematic findings that emerged from the data gathered in Seoul in November 2015 and in July 2016[41]. The interview data were coded based on the themes generated from the York and Berlin studies. These themes were employed as orienting topics but were flexible so that they could be modified if and when new elements were emerged. Finally, by accumulating the findings from the three cities, the thematic concepts for understanding the role of portable air-quality sensors in urban air-

[41] The participants or interpreter were speaking in a second language, hence some of the English usage is inconsistent. The last interview was conducted in Berlin.

quality monitoring and management, as well as the participation of end-user stakeholders, were established.

6.3.1 State and progress

Theme description

State and progress refers to the legislative requirements for air-quality monitoring and management, as well as the current situation with respect to the monitoring network and communication practice in Seoul. More specifically, it covers:

- policy development and the progress of the air quality agenda,
- emission control policies (especially transportation),
- political systems and organisations with respect to air quality management,
- perceptions of the development of monitoring techniques, and
- use of generated air quality data and information provision.

The theme captures the current situation and the change of air quality in Seoul according to the participants' background and experience. First, it reflects the *state* of the air quality, as well as the legislation and policy measures for monitoring and managing the issue. The second subject in the theme is the *progress* of introduced policies. Together the two parts formed the context for the rest of the analysis and provide the basis for understanding the primary function of air-quality monitoring in Seoul.

Air quality is a key environmental challenge in the highly urbanised Seoul Metropolitan City, despite the recent ten-year efforts in the capital region for improving air quality (Lee et al., 2015; Ministry of Environment, 2015c; Seoul Metropolitan Government, 2015d; Chambers et al., 2017). Although the goals of the improvement strategy to reduce the concentrations of PM10 and NO_2 to the levels of Tokyo (40 $\mu g/m^3$) and Paris (22 ppb) by 2014, were not attained. PM10 concentrations decreased from 69 $\mu g/m^3$ to 41 $\mu g/m^3$ over 2003 to 2012 but rebounded to 45 $\mu g/m^3$ in 2013. While NO_2 reduced to 33 ppb in 2014 from 38 ppb in 2003, it still slightly exceeded the standard of 30 ppb. In 2016, the levels of PM10 and NO_2 in Seoul were 48 $\mu g/m^3$ and 31ppb, respectively. As such, PM10 satisfied the national air quality annual average standard of 50 $\mu g/m^3$ while NO_2 did not (Seoul Metropolitan Government, 2017e). And there is no clear reduction: the concentrations '*just stay, up and down*' (Interviewee_S1), and '*still NO_2 is a very big problem in our metropolitan area*' (Interviewee_S5).

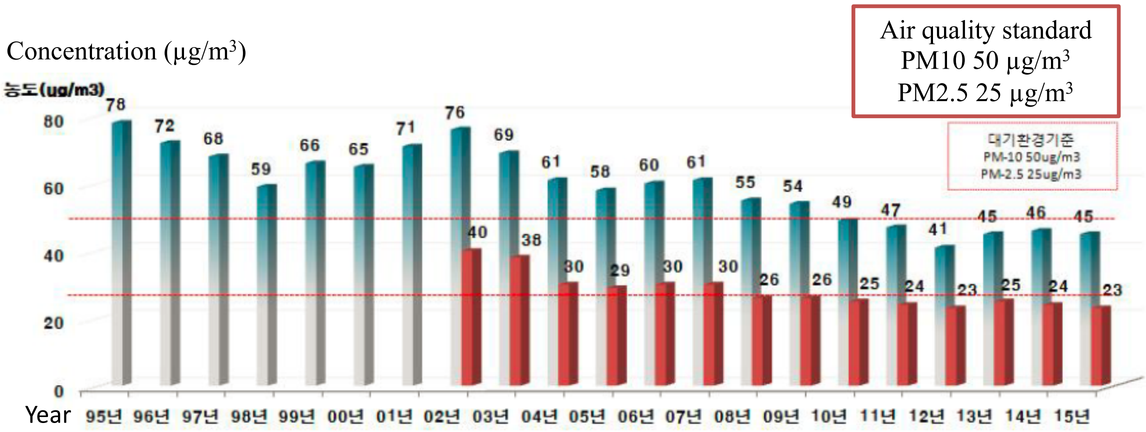

Figure 6- 8 Changes of annual concentration of PM10 and PM2.5, modified with translation (Seoul Metropolitan Government, 2016)

After the first phase of the planning, new targets have shifted from concentration reduction to receptor-oriented risk-management (human health focused), and more atmospheric substances such as PM 2.5 became a concern. Reducing PM2.5 concentration is highlighted in the capital area's recent policy framework, the 2nd Seoul Metropolitan Air Quality Improvement Planning (Ministry of Environment, 2015c). At the municipality level, this is reflected by the ambitious blueprint, 'Four Year Plan for Seoul', which aims to reduce the concentration of PM2.5 by 20% by 2018 compared to the level of 2013 (from 25 $\mu g/m^3$ to 20 $\mu g/m^3$) (Seoul Metropolitan Government, 2017c).

The participants raised different aspects of the air quality situation in Seoul. On the one hand, the interviewees were aware of management efforts and progress (Interviewee_S1, S4, S6, S10). For example, interviewees reported: '*in general the SOx, NOx and other air pollution are quite well managed and controlled*' (Interviewee_S4), '*a big difference*' was observed with respect to the PM concentrations (Interviewee_S6), and one interviewee suggested '*for SO_2 or TSP or CO is very good now'* (Interviewee_S10).

On the other hand, the participants also shared their worries about the management of NO_2 (Interviewee_S1, S5, S6, S10), ozone (Interviewee_S1, S5, S10), VOCs (Interviewee_S1, S4, S10), and in particular, PM2.5 (Interviewee_S1, S2, S4, S7, S5, S10), as well as the stringency of the standards

(Interviewee_S1). There was a consensus that air pollution abatement is complex and requires a clearer understanding of emission sources and that various measures that would be involved, from the management of transport (Interviewee_S1, S2, S3, S5, S6, S10), domestic heating (Interveiwee_S1, S10) and restaurants (Interviewee_S10), to the secondary formation of particulate matter due to chemical reactions in the atmosphere (Interveiwee_S1, S5), as well as the cooperation between different levels of governments (Interviewee_S1, S2, S3, S5). Nevertheless, the majority of the participants believed that long-range transboundary air pollution is a major issue for Seoul as well as for South Korea, especially for lowering the PM 2.5 concentrations. Interviewee_S1 reported:

> *…when the long-range transport happened from China to Korea, and then PM2.5 concentration becomes very high (…) So the impact with respect to that quantity, the concentration of PM2.5 is going to be more than 60%. So we think the long range transport impact going to be about 40%, entire year, so it's huge impact.*

Although participants pointed out that specifying the impacts of domestic and transported emission is difficult, due to the chemical formation (Interviewee_S1, S2, S5), it is a great concern in general, as reflected in the following:

> *Air pollution, because air pollution in winter, we feel is a very serious problem with the wind from China, very serious. [Interviewee_S6]*

Indeed, the air quality situation of Seoul and PM2.5 management, in particular, is complicated and questions remain: are different stakeholders *aware* of air pollution? To what extent are they *willing* to put in effort to reduce the level of pollution? Which actors are more *powerful and influential* with respect to air quality management in Seoul? Who is ultimately *responsible*? And how can monitoring contribute to the reduction of air pollution? The following discussion highlights these questions and provides some answers.

6.3.2 Awareness and willingness

Theme description

Awareness and willingness refers to the public and political awareness of urban air pollution and willingness to address the issue. Specifically, it covers:

- knowledge of the availability of air quality information and how information is perceived amongst the end-user stakeholders;
- understanding adverse impacts of air pollution and willingness to take action to reduce the impacts;
- the extent to which air pollution is treated as a policy priority by the authorities and the political will to address the issue
- awareness of self-responsibility

This theme captures the views of the public and the city authority as in the previous city case studies. It encompasses awareness of air pollution, its solutions and whether and how end-user stakeholders are motivated to tackle concerns.

6.3.2.1 Public awareness and willingness

The findings indicated that the level of public awareness of air pollution is fairly high in Seoul. These interview findings are also supported by previous studies: according to a public survey conducted in 2011, 51.8% of the citizens in Seoul consider air quality as the city's imminent environmental issue, and 68.3% of the respondents view the level of air pollution as serious (See Figure 6- 9 and Figure 6-10) (Woonsoo Kim et al., 2011).

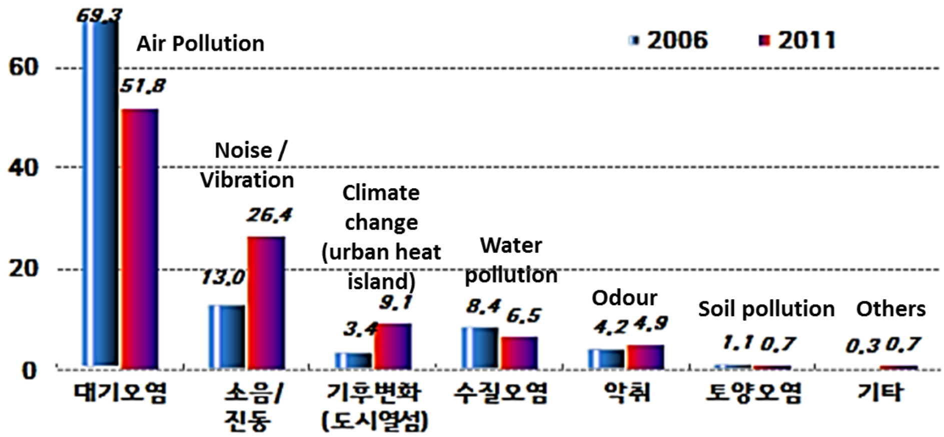

Figure 6- 9 Survey on public awareness of environmental priority in Seoul Metropolitan City, 2006 and 2011 respectively (Woonsoo Kim et al., 2011)

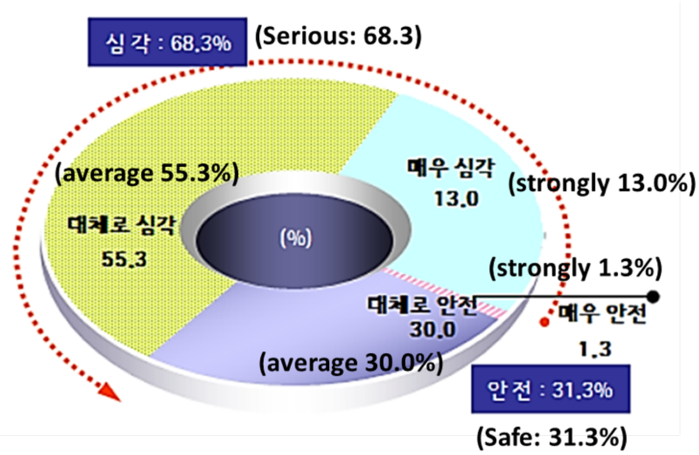

Figure 6- 10 Public opinion about air quality in Seoul Metropolitan City (Woonsoo Kim et al., 2011)

Further, the responses indicated that the public is also aware of the impact of air pollution on their health and daily life. One respondent reported:

> *'because they know that the smog is harmful to the health, people very much like to walk or climb, or exercise and they know that exercise during the smog is quite harmful for the health, so that's why people are very much concerned about the reports, forecast of smog.' [Interviewee_S3]*

The responses revealed different factors that affect public awareness levels. Firstly, the participants commented on the positive impacts of the information provision system in Seoul. Interviewees expressed the view that through the official forecast and warning systems, the public is well-informed about air pollution levels (Interviewee_S1, S4, S5, S6). Secondly, it was also found that mass media reports increased people's concern about air pollution issues (Interviewee_S1, S3, S4, S6). The visibility of the problem also explains why PM pollution is an increasing concern:

> *…especially PM, they don't know PM10, PM2.5, but they feel and they saw the bad visibility from time to time, so they feel, uh my health might be a big problem. [Interviewee_S5]*

However, although the public is aware of the issue and its impacts, interviewees espoused the view that citizen willingness to change their behaviour is low (Interviewee_S2, S7, S10). One participant said:

> *Only concerns increased. We only like blame about it but we don't really like trying to change our behaviour. [Interviewee_S2]*

One reason behind that, as reflected by the participants, is that the PM levels are normally high in winter, indicating the seasonal nature of smog (Interviewee_S1, S3, S5, S6). Interviewee_S3 reported:

> *I mean top priority maybe, frequency is about smog, yes, but smog is seasonal issue, during summer time we do not have that, so only from autumn to early spring, winter season issue. (…) in our cases, I think some chemical issues, risk from carcinogen or some others those kind of issues are more important for ordinary people I guess.*

The participant further explained the change of public view on air pollution from a historical perspective. In the 1980s and 90s, environmental pollution, including air and water, was a major social and political topic in the South Korean environmental movement, which was regarded as the '*front-runner*' of the democratisation movement. At that time '*environmental sentiment was very high*' (Interviewee_S3). Yet once democratic institutions, including an environmental administration, were establised, public attention waned (ibid.). The focus of environmental concerns shifted to various issues such as energy, climate change and biodiversity (ibid.). Air quality management and communication is seen as an administrative issue and a duty of the government:

> *…we feel that they are now under the control of the governmental organisation, I mean local government and central government can handle it and we can trust them to do it. [Interviewee_S3]*

Further to lacking interest in daily life, people are reluctant to '*accept we need to reduce the use of vehicles*' (Interviewee_S2) and hold a NIMBY (not- in-my-backyard) point of view (Interviewee_S10).

In addition, the findings indicated that the public is aware of transboundary pollution from China, especially in the winter season (Interviewee_S1, S2, S3, S5, S6, S10). One interviewee said:

> *The citizens worry about some serious situation like some days, influences from China, the wind from China, so the influence in Seoul. [Interviewee_S6]*

And given the recent visible high levels of air pollution and the changes in international relations with China due to the deployment of THAAD missile system[42], air pollution has emerged as an increasing social concern in South Korea that may have contributed to anti-Chinese sentiment (Korea Bizwire, 2017; Volodzko, 2017).

The participants' views, on the one hand, commented the public opinion on long-range transported emissions. On the other hand, the findings suggested the need to focus on local sources of emission. One respondent said:

> *In Korea actually, the particulate matters, the cause of particulate matters it varies, because some people insist they are coming from the China (...) so the various factors should go together to manage this kind of environment, for example, to control the vehicles. [Interviewee_S2]*

Equally, interviewee_S5 explained the necessity to consider local sources as well as the long-range transport emissions with respect to the levels of PM2.5, as '*it's all kind of mixing*' (Interviewee_S5]. And for the concentrations of NO_2, there is need to tackle the domestic sources:

> *But in case of NO_2, we can't not control, still, NO_2 is a very big problem in our metropolitan area because we have too many cars, too many other reasons.*

Increasing public concern about air pollution is driving policy initiatives. For instance, the most recent air quality plan is oriented to public health protection (Seoul Metropolitan Government, 2017c). The interpretations of public awareness and willingness towards air pollution and their relative positions are plotted in Figure 6- 11, the comments of the participants are shown in Table 6- 1. As the level of willingness is generally low, only 'strong' is used to illustrate the spectrum.

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[42] In July 2016, South Korea agreed with the US government to deploy the THAAD missile system (US Army's Terminal High-Altitude Area Defence) as a response to North Korea's nuclear test. However, the Chinese government against the action, worrying about the impact on its security system and consequences on addressing the Korean disputes (The Guardian, 2016)

The results show that a majority of the responses reflected a high level of public awareness of air pollution in Seoul. And there is a consensus among the study participants that the level of public willingness is very limited. Hence, a high level of *awareness* of air pollution with the public does not translate in to an increase the *willingness* to take action.

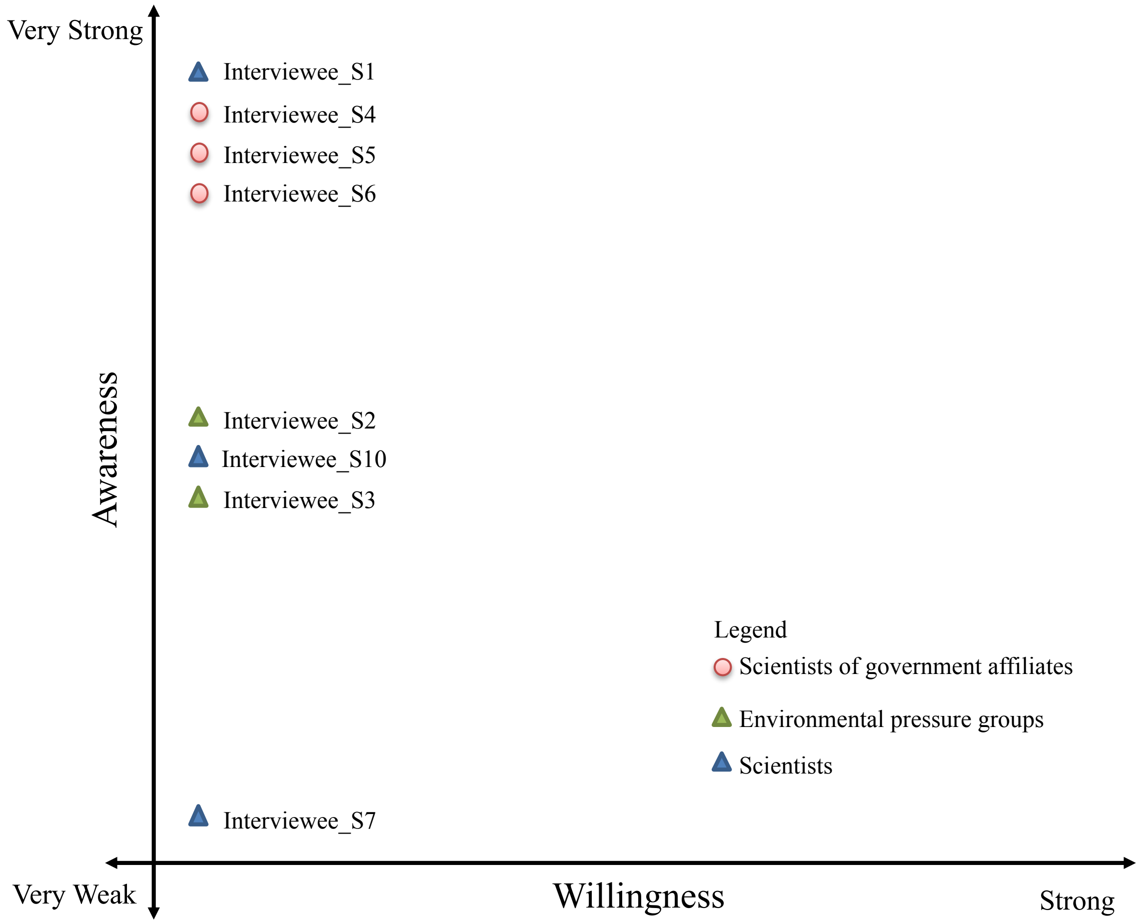

Figure 6- 11 The relative position of participant interpretations of public awareness (on y-axis) and willingness (on x axis) regarding air quality in Seoul.

Table 6- 1 The comments of interviewed participants on public awareness and willingness regarding air quality in Seoul.

Interviewee	Interpretation of public awareness	Interpretation of public willingness	Comment
S1	Very strong	Weak	'…yeah, surely, yeah, especially, except summer time, (…), especially when you know PM2.5 is transported from China to Korea.'
S4	Very strong	Weak	'the civil organisation is quite well-informed about the current environmental pollution.'
S5	Very strong	Weak	they feel, and they saw the bad visibility from time to time, so they feel, 'uh my health might be a big problem'.
S6	Very strong	Weak	'the citizens worry about some serious situation like some days like influences from China, the wind from China, so the influence in Seoul.'
S2	Strong	Weak	'First rank is the air pollution. (…) Only concerns increased. We only blame about it but we don't really like trying to change our behaviour.'
S10	Strong	Weak	'The problem is that they think most important issue is air quality but is their, this person he said, is not their own problems, that's the problem.'
S3	Strong	Weak	'I mean top priority maybe, frequency is about smog, yes, but smog is seasonal issues during summer time we do not have that, so only from autumn to early spring, winter season issue. (…) I think some chemical issues, risk from carcinogen or some others those kind of issues are more important for ordinary people.'
S7	Weak	Weak	In Seoul area, because of the high traffic, because I know the air quality, but somehow the local people, residents in my area they feel ok.

6.3.2.2 Political awareness and willingness

The findings revealed that the national government and municipal authority have a good level of awareness of the importance of managing air quality. They also have the political will to address the issue. For example:

> *the government officers are quite keen to implement and make the legislation or regulation effective. [Interviewee_S4]*
>
> *…Mayor Park started his second term from two years ago; so he set up new goals of air quality, especially for PM2.5, fine particulates. [Interviewee_S10]*

The political awareness and willingness are also reflected in policy-making. For instance, this is seen in the implementation of the Special Act on the Air and its improvement framework plans, as well as the city's own master plan (Ministry of Environment, 2015c). Although the respondents reported that the change of policy measures and political mind-set happened only recently.

Interviewee_S1 reported:

> *…they just changed about the environmental policy paradigm, (…), there's a growing demand for receptor-oriented environmental management (i.e., public health focussed) policies that comprehensively account for the impact of harmful substances on public health and ecosystems. Accordingly, air quality management policies are also shifting towards a risk orientated policies.*

Another respondent added that the government just realised the importance of sophisticated measurements and modelling for policy-making. Because policy measures are often costly, '*which is money*' (Interviewee_S5), therefore, necessary interventions and consequences should be better analysed before the implementation of policy measures in practice.

Additionally, the participants also noticed that political will varies at different levels of the government, and there are tensions between the administration and civil society regarding the approach to air pollution control measures. One interviewee said:

> *…in central government it's not active because our economy is not so good and other problems, just we think our government more oriented the economy rather than the environment. [Interviewee_S10]*

Regardless of the differences, the responses of the interviewees indicate that the forces behind the political awareness and willingness are mainly increasing public concern (S1, S3, S5, S10) and scientific work and findings (Interviewee_S4, S5). For example:

> *… so public like think ok what our government is doing about this long range transport? I think a lot mass media just kept pushing this government people, so they decide start to regulate from this year. So it's more like I think the public inputs made this really happen. [Interviewee_S1]*
>
> *The media and also the research papers; we make our research in public and it gets some attention from the civil societies and civil organisations. [Interviewee_S4]*

Amongst civil actors public concern and mass media reports play a central role. The city authority is also aware of the essential role of public engagement in air quality management and made efforts to promote behaviour changes (Interviewee_S3, S6, S10). An example given by the participant illustrating the public participation in environmental issues is the 'Eco-mileage System' (Interviewee_S6). It is an incentive programme launched in 2009, primarily aimed at improving energy efficiency and reducing energy consumption and also positively encouraged the use of public transportation (Seoul Solution, 2014). One respondent pointed out that the large number of vehicles in Seoul is a primary source of local emissions, '*they're the main causes*' (Interviewee_S2). Other participants further explained the rational for citizen's participation in air quality issues:

> *In the past, it's almost government built air quality policy, but right now the air pollution situation is not so improved from maybe several years ago; so right now we should more focus on the citizens' participation to control traffic volumes and whatever. [Interviewee_S10]*
>
> *People's participation means people are accepting responsibility. If people don't participate, they would not take any role, they would not share the burden with the government. Only when they participating the process they are willing to share the burden of the government in environmental monitoring. [Interviewee_S3]*

These claims imply the role of public responsibility, and also relate to the potential for political influence of the mass media or civil society in the broad sense, which are picked up below in the discussion of the theme on *power and influence*, and *responsibility* (see below).

The findings also indicate that high profile and prestigious international events could affect the political view of air pollution and can be a window of opportunity. For example, the 1988 Summer Olympics held in Seoul changed the political will with respect to pollution data:

> *…because they say that it would make people who live in the higher polluted areas feel that unhappy, because their house prices go down, that reason. So that's the way of thinking of government officials before Seoul Olympic, but after that, they decided to open all the measurement data of pollution, water and air. [Interviewee_S3]*

And the 2002 FIFA World Cup in South Korea and Japan:

> *In 2002 we hosted a world cup game, Korea-Japan world cup game; at the time our NGO group worked with Japanese NGO group together to monitor air quality in Seoul area, Seoul and other nearby area, and then some Japanese cities to monitor NO_2. (…) So that was good event but after that no such kind of activity. [Interviewee_S10]*

Studies have shown that hosting prestigious events often has an impact on urban development (Essex and Chalkley, 1998, Andranovich et al., 2001). The above responses implied that with respect to air pollution in South Korea, high-profile events changed political attitudes as policy-makers were concerned about South Korea's international image. The quote also demonstrated that the government's recognition of the importance of transparency and openness in environmental governance (Interviewee_S3, S10).

The interview findings show that from both public and political perspectives there is a high level of awareness of air quality in Seoul, but the level of willingness to address the issue differs. The interviewees suggested that there is a lower public willingness compared to the municipal governments' political will. The results may be due to the fact that air quality is a low priority in relation to public domestic concerns. It may also reflect wider public understanding that controlling emissions only partly rests in South Korea's hands due to issues of transboundary air pollution. Yet, according to the responses, public engagement in addressing urban air pollution is essential; political will needs to be allied with the public actions.

6.3.3 Power and influence

Theme description

Power and influence refers to the capability of end-user stakeholders in terms of introducing any change in monitoring and managing local air quality activities. Specifically, it covers:

- possession of resources needed to establish air-quality monitoring practice and to implement control measures,
- legitimacy and political influence with respect to local air quality management,
- development and take up of new monitoring technologies, and
- public and policymakers' perceptions of non-regulatory monitoring and what the interests of end-user stakeholders are.

Administratively, the Seoul Metropolitan Government operates the air-quality monitoring-network in the city, providing air quality information to the public through various channels, including air pollution warnings and forecasts. The processed results are also sent to the Ministry of Environment and published on a national website designated for air quality information. A majority of the participants agreed that, in general, the monitoring and information provision of air quality is efficient in Seoul. Both the national government (Ministry of Environment) and the municipal government invested in the establishment of monitoring systems:

> *So to do that system actually Ministry of Environment invest a lot of money to develop some models to predict this PM2.5 or PM10 concentration in advance. [Interviewee_S1]*

> *'Mayor Park wants some kind of governance side, so they are trying to open as much as possible and that, … I think the website is quite efficient. [Interviewee_S10]*

Another interviewee further added:

> *So I know that personally, the government people are very very strict in measurement, so they realise that it's really important to get trust from ordinary people, especially for the measurement. [Interviewee_S3]*

The findings also revealed the financial capability affecting the environmental policy-making and policy agenda:

Cause they're going to spend I think more than 100 million dollars for this next 10 years. (...) So for the first stage they just focus on decreasing the concentration, (...), only what they can said at that time was the concentration was decreased from this to this, so we invested this kind of budget to improve this air quality but public doesn't care about that, cause they more care about their health. They try to persuade the government people to show how they increase the human health effect by investing this huge amount of money. That's why they change the vision also of this air quality improvement planning from first stage to second stage. [Interviewee_S1]

The above responses reveal the interviewees' perception of the influence of the civil society on air quality policy. As reported in the previous theme, the citizens in Seoul are concerned about air pollution, and according to the interviewees this public attention drives the policy-makers to focus more on the health dimensions of air pollution.

It also implicitly indicated the cross-governmental management approach of air quality issues and the position of environmental administrations. Another interviewee said:

…especially it's clear in the field of climate change. ... who controls the industries which emit carbon dioxide in Korea? It's not the Ministry of Environment, it's Ministry of Industries. In Korea, Industry ministers are stronger than Environment ministers. (...) Legislation in that field, for example, carbon marketing or other facility or registrations we don't have. [Interviewee_S3]

With respect to the control of emission sources, the metropolitan government implements policy intervention to reduce the traffic emissions, for instance by providing subsidies the city has converted the buses operating in Seoul from diesel to CNG (compressed natural gas) buses (Interviewee_S4, S6). Yet, the participants identified that a wider range of collaboration with other governments in the Metropolitan Area is needed in order to reduce traffic emissions further, as even for the local emissions the city could not prohibit diesel buses entering from other areas to Seoul (Interviewee_S4, S5, S6, S10). Besides, the national plan has a strong influence on the availability of funding and the enforcement of control measures at the municipal level. The levels of pollution are attributable to various emission sources in the region, thus, a different policy focus presents itself. Interviewee_S10 said:

… because our central government, Ministry of Environment, has its own policy to improve air quality in Seoul metropolitan area. (...) So they have different agency (...) that agency is managing total air quality policy. Also, they are subsidising some budget from central

government to local government. So local government like Seoul City, (…) they are mostly dependent on the principle of central government. But the problem is, (…) this big area has different situations; (…) but for the Seoul City itself, most important thing is the transportations. So Seoul City should focus more on the motor vehicles, but there are not so many tools to regulate [Interviewee_S10]

In addition to domestic emission control, there is also a good deal of concern about transboundary air pollution (Interviewee_S1, S2, S3, S5, S6, S10). Hence, governments at national and local levels are active in establishing international dialogue, which one interviewee suggested had been influential through ministerial meetings and municipal agreements (Interviewee_S1, S6). For instance:

nowadays every year the Ministry of Environment chief in Korea, China and Japan gather (…) So I think especially for China they try to make very strict air quality standard nowadays, because of the result of this meeting between the three countries… [Interviewee_S1]

The findings grouped under this theme indicate the position of the Seoul Metropolitan Government and the possible influence of the public upon the local policy planning. It explains the changes of policy development with respect to air quality management and illustrates that there are different viewpoints about who should be responsible for mitigating air pollution.

6.3.4 Responsibility

Theme description

Responsibility refers to the liability and duty of end-user stakeholders in monitoring and managing local air quality. It emerges from:

- possession of resources which are needed to monitor and/or improve air quality,
- distribution of impacts and accountability of the management organisation
- scales of responsibility due to the impacts of air pollution (for example, local or national, personal)
- types of responsibility (legal or ethical)
- distribution of responsibility for data management

This theme extends the discussion of power and influence. It also explores the impact of awareness and willingness of those who should be responsible for controlling and managing air quality. The responsibility of the government, environmental pressure groups as well as the general public are the main aspects that emerged from the qualitative data.

As mentioned in the previous sections (section 6.1.3 and theme of power and influence), the responsibility of the government at different levels lies with the management of the air-quality monitoring-network and control of air quality concentrations. Central government operates the national and regional monitoring networks and the municipal authorities are responsible for the local networks. The interviewed participants drew attention to the different air quality measurement systems, as well as the distribution of responsibilities (Interviewee_S1, S5, S3, S10). Interviewee_S3 said:

> *Government monitors all kinds of emissions, but central government and local governments they have their own responsibility, for example, central government is monitoring this highly, some industrial complex and local government dealing with their own industry. [Interviewee_S3]*

In Seoul, the city authority is in charge of the monitoring stations in its 25 districts (Gu) and the monitored air quality data are automatically sent to the Seoul Research Institute of Public Health and Environment under the Metropolitan Government for website publication (Seoul Metropolitan Government, 2016). The data are also shared with the national administration after quality control and are published on the national air quality information website (ibid.). According to the participants, both the national and local monitoring systems, as well as the information platforms for air quality forcast and warnings, are well established and maintained (Interviewee_S1, S3, S5, S6, S7, S10). Yet, the participants noticed the advances of Seoul in terms of monitoring air pollution. For instance, the warning system of Seoul is '*very different from the central government one*' (Interviewee_S10). And Interviewee_1 said:

> *The Seoul city actually has their own warning system for the fine particles, so PM2.5 and PM10 specially. They have a higher standard that means stricter standard than national level of PM2.5 and PM10 warning system level.*

Despite the management efforts in strengthening the requirements for informing the public of the level of air pollution, the findings revealed the need to improve the siting requirements for air-quality monitoring. Interviewee_S3 mentioned that there was a long-term discussion between the environmental groups and the government about the monitoring sites:

> *…at the same time they raised the issues about the location of the measurement stations, for example, government wants to place a measurement station in some safer area, I mean, from the point of control, I mean, they want to install that outside roof side of a governmental official building, so it's stable, and they can easily control. But civil groups argue that it's nothing to do with ordinary people's daily lives, make it to the ground...*

Concerns about the monitoring network have not only been raised by civil groups. Interviewee_S2 added that there was political critique of measurements to reflect the personal exposure:

> *This year the one politician pointed out that, (...), there's equipment measuring and (...) the equipment should be within the ten metres' height. But (...) the current equipment is set up more than ten metre height which is not very appropriate to measure the air pollutants accurately. (...) even though we gather the data (...) if that one's really reflect the residents' exposure to air pollution?*

With respect to the level of air quality concentration, the Seoul Metropolitan Government has the duty of managing local emission sources. As traffic is an important local emitter, the authority has implemented policies to reduce emissions from traffic (Interviewee_S2, S4, S6, S10). Nonetheless, the findings revealed that car users share the responsibility in reducing the traffic emissions, as they are '*using their vehicle a lot*' (Interviewee_S2). However, the public often lack awareness of their own responsibility. Interviewee_S10 said:

> *The problem is that they think most important issue is air quality, but (...) this person he said, 'is not their own problems', so, that's the problem.*

Interviewee_S2 echoed the opinion and explained that it is difficult for the citizens to '*accept we need to reduce to use the vehicles*'(Interviewee_S2).

A majority of the responses mentioned that transboundary pollution from China has a significant impact on the pollution level in Seoul, in particular with respect to the PM levels (6/10). Despite the difficulty in distinguishing the external emissions, previous studies also show that the high level of PM10 is affected by the transported emissions from China and the Gobi Desert especially in winter and spring (Lee et al., 2011, Lee et al., 2013, Oh et al., 2015). Thus, the national and local governments engage with the international community to promote cooperation and share know-how (Interviewee_S1, S3, S6, S10). For instance:

> *So many people understand when we say international cooperation is important, at some stage of development, those kind of pollution is not avoidable. So we help, we provide them with suitable technology or know-how so that they can overcome the problem soon, so that's the best way we could do. So I think the government is in that way of treating these issues. [Interviewee_S3]*

> *Sometimes we know yellow dusty ... from desert, also the serious situation. So we suggest China to reduce the desert. Also, we supported, make plan with voluntary sector. [Interviewee_S6]*

Additionally, the findings revealed the responsibility of scientists in communicating the monitored air quality data and the important role of environmental groups. According to the responses across the professions, the atmospheric scientists and modellers transfer the abstract measurement data into scientific evidence for authoritative decisions and interpret the results in a comprehensible way so that the general public can easily understand (Interviewee_S1, S4, S5).

Interviewee_S3 said:

> *Of course ordinary people complain the quality of air pollution, the air they breathe, but they don't know how to measure the pollution level, or what's the meaning of the environmental criteria, so it's quite technical, and people hardly understand them. So the environmental groups opened a kind of environmental pollution school (...) to educate ordinary people and future activist. (...) details about what we measure in the air, how to measure, what is the meaning of criteria, something like that, why it's important.*

The respondent further added such presentation of air quality analysis increases pressure on related authorities, enforces internal collaboration and government accountability:

> *For example, scholars who are member of this school, environmental school, who can access all the government air pollution data from minute by minute data, and he analyse it with his computer and open it to media that government air pollution policy is failed, something like that. This kind of use government also know, but the government would not stop providing data to him because government think that by doing that his ministry gets also, I mean because you*

> *know the air pollution policy is weak because their financial situation is bad, something like that. They know that, so this kind of civil activity is beneficial in the long run. [Interviewee_S3]*

From the above responses, it is revealed that the environmental pressure groups are direct users of air quality data. They are knowledgeable about air quality and are willing to translate potentially abstract data into understandable information for raising the awareness of general public and to call for policy interventions. As such, this end-user group has taken a normative position in which it takes responsibility for improving local air quality, although they do not have a legal obligation to do so.

6.3.5 Technological innovation

Theme description

Technological innovation refers to the potential impacts of sensing technology on managing local air quality, it involves:

- availability and features of non-regulatory air quality sensing technique,
- concerns about the challenges of the innovation,
- potential cost and benefits
- forms of information provision

This theme discusses the potential uses of non-reference air-quality monitoring techniques and the function of communication platforms in Seoul's air quality management.

The responses convey the idea that the introduction of non-standard air quality sensing techniques has potential benefits, especially for atmospheric scientists to meet various research purposes. First, more air quality measurements could improve model resolution by providing additional data that standard monitoring networks do not offer (Interviewee_S5, S6). For example, Interviewee_S5 mentioned that air quality is '*controlled by the mixing* (of atmospheric pollutants as well as the metrological conditions)'. Thus, a vertical profile of air quality would be necessary in order to build a three-dimensional model to predict the movement of atmospheric pollutants. However, the current air-quality monitoring-network focuses more on ground concentrations. The non-stationary techniques, for instance, flight observation and drones, can provide vertical datasets and improve model performance (Interviewee_S5). In addition, Interviewee_S1 reported the benefits for health studies to understand the association between individual exposure and concentrations of air pollutants. Such research outcomes can also inform the policymaking:

> *For example, automobile emissions, (…) the contributions from that emissions gonna be high in rush hours during the morning time and night time. And then if you can compare that result to like emergency visiting from like certain respiratory or cardiovascular related diseases and then you can come up with all good idea about this emission effect to human health. And then you can make some very strict strategy to control the automobile emission in that rush hour maybe. So that kind of example, you can have a lot of very 'real-time strategies' [Interviewee_S1]*

The data generated from portable devices are also regarded as part of the urban big data and have '*good analytical power*' and benefit the public by providing real-time air quality information (Interviewee_S1, S3). One participant said:

> *This kind of new technologies are more individualistic (…) we could know what you want, what you eat, where to go, this kind of things if it's used for environmental monitoring, it's really beneficial for all of us, if it's not misused. [Interviewee_S3]*

Yet, the findings also revealed the limitations of non-routine monitoring practice. For example, Interviewee_S1 noted that even though big data provide detailed personal exposure information, in order to generate scientific results effectively, it is necessary to have '*analysis technique dealing with this kind of big data system*'. Further to that, other informants pointed out that such monitoring practice requires sufficient financial resource to support the operation:

> *…would be very useful, but there is always some problems of money and budget and the operational cost. [Interviweee_S4]*

Another respondent captured the same point and implied that the expertise is another important element from data collection to data analysis by saying:

> *(…) for the collecting data, maybe you can connect with some NGO network and then maybe some participation of the public, maybe some you can select some citizens. Those kinds of activities are really very important to collecting data, and then maybe we can prepare some maps, monitoring maps, and there should be somebody to analyse the situations, right? [Interviewee_S10]*

The above comments also revealed the concern with respect to data quality and reliability of new forms of air-quality monitoring. The interviewee further commented the limitation of mobile sensing in official monitoring due to the performance of the sensors and its dependence on the property of the atmospheric pollutant compared to the established techniques:

> *The government people is arguing about the accuracy (...) But there have been some development in terms of the sensors, sensing the gaseous pollutant easier than the particulates, better. So it depends on the types of air pollutants. Sometimes it can work but sometimes it doesn't. [Interviewee_S10]*

Another limitation emerged from the responses is a result of the well-established information sharing infrastructure in Seoul (see Figure 6- 5). One respondent critiqued the functionality and necessity of applying personal sensing devices in saying: '*why do you need air quality information on your hand?*' [Interviewee_S7]. Interviewee_S3 explained this and emphasised that the policy implications of air quality data are more important to the environmental pressure groups:

> *Environmental data itself is not that important for environmental groups these days. (...) NGOs and activists want not data, but some documents which contain the governments' plan, or future intention, so it's not data, but some policy, I mean not exact data, data is not important, data open, all of us have it.*

Figure 6- 12 The air-quality monitoring equipment (left), mobile monitoring van (middle) and information control room (right) in Seoul.

Apart from the limitations caused by the technology competence, respondents identified the different needs of air quality data in different uses. The point was captured by Interviewee_S8 who reported:

> *It depends on the consumers like if you are expert, you want to see more detail, more accurate data, but if you are just like resident, just common consumer, you want to see not too much accurate, but kind of general data.*

Similarly, Interviewee_S9 specified that atmospheric scientists and the general public have different demands for monitored data quality in saying:

> *If we are going for the research and development, in that sense we need to have higher accuracy data and we need to focus on sophisticated instrument, but for the general public and awareness, because sophisticated instrument is not like feasible in their sense like this smart instrument, this (new technique) will be very popular [Interviewee_S9]*

Another interviewed participant echoed these opinions and implied that an information infrastructure is essential for both voluntary and official monitoring:

> *I think it's issue separated, for official data, maybe the government they should work, but for public awareness then maybe if we can think about this kind of very handy monitoring systems. But it's very important to develop some very stable and accurate sensors and some IT-based communication networks. [Interviewee_S10]*

The findings disclosed that the application of new forms of air-quality monitoring using portable sensors in Seoul is relatively limited due to the well-established of information provision systems of regulatory monitoring, the technical performance of present air-quality sensors as well as the investment required. Despite all the constraints, new type of air-quality monitoring using portable sensing techniques could benefit research in air quality studies (Interviewee_S1, S5) and fit individual needs by providing personalised information (Interviewee_S1, S3).

6.4 Linking the grounded theory themes

This section links the identified themes from the analysis of the qualitative data in the case study of Seoul. The contents of each theme are updated as a result of the accumulation of thematic analysis of the three cities. The themes emerged from the qualitative data are 1) state and progress, 2) awareness and willingness, 3) power and influence, 4) responsibility, and 5) technological innovation. Of these, the theme of awareness and willingness underlines the issue of air-quality monitoring and connects the other topics. The relations of the themes can be found in Figure 6- 13.

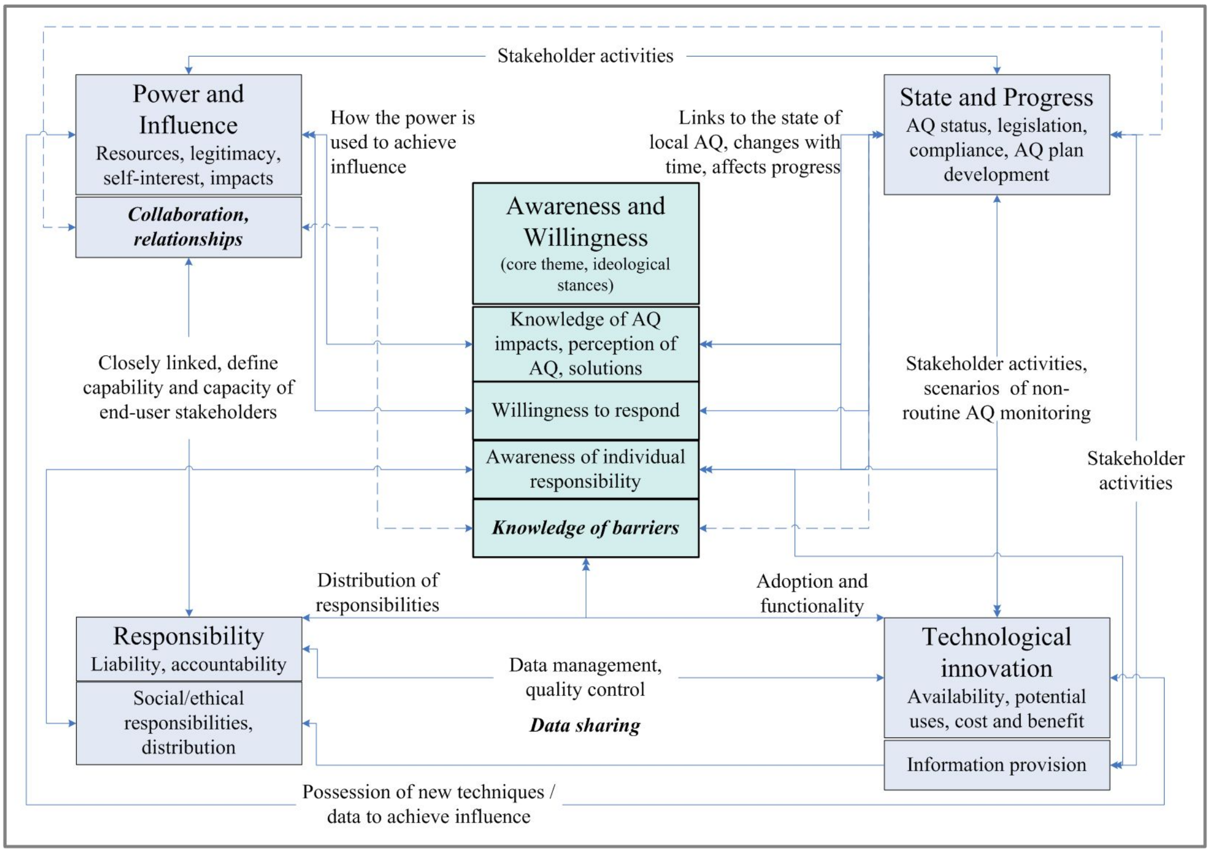

Figure 6- 13 Relations between the developed grounded theory themes in Seoul, details added in italic

The political context in Seoul mainly concerns the political willingness to reduce PM2.5 levels and the international context of trans-boundary air pollution management. Unlike York and Berlin, the national government made air quality improvement of Seoul a priority on the national policy agenda. The capital also has a considerable degree of autonomy to set the city's own air quality standards and strategies to achieve the targets. The interviewees also suggest that the mayor of Seoul is committed to improve air quality, with respect to PM2.5 in particular. As such, the metropolitan government has made ambitious policy goals to reduce concentrations of PM2.5. Yet, there is a strong influence of trans-boundary air pollution. The presence of international sources on the one hand drives public and political awareness of the issue but simultaneously can disincentivise domestic action. Nevertheless, the findings suggest that international cooperation is key for addressing the city's air pollution problem.

The central theme, Awareness and Willingness, reveals different understandings of air pollution and its implications in Seoul among end-user stakeholders. The first subject of awareness is informed by the state and progress (theme one) of Seoul's air quality. It reflects that due to the seasonal low visibility and established information provision channels, both public and political awareness of the pollution issue is high. The political awareness results in a good level of willingness to intervene in emission control and is reflected through the progress of air quality management policies. In contrast to York and Berlin, there is evidence to suggest that most of the public is aware of air pollution and its adverse impacts to health. However, the level of willingness to control domestic emission sources is limited when it requires behaviour change in particular, i.e., to reduce the car use. The interviewees suggested that there is a limited public awareness of self-responsibility, which in turn affects administrative influence. The results reveal the importance of the local authority being aware of the challenges from multiple aspects to the improvement of local air quality. Thus, the barriers are added to the theme content as a result of the analysis.

The theme of power and influence explores the relations between capability, awareness and willingness of end-user stakeholders and the state and progress of air quality. For Seoul, the metropolitan government has the resources and willingness to improve local air quality and engage with the general public. Yet, an effective air quality management plan requires in depth collaboration with other administrations within the local government, regional authorities in the metropolitan area, and international communities. International collaboration and cooperation are particularly essential to address transboundary atmospheric pollutants. The findings also reflected that the public willingness to take action is a critical factor in managing local air quality. The awareness of self-responsibility, the challenges of increasing social acceptance of policy measures, the importance of information accessibility for the general public, are all as important as being aware of the pollution and its impacts.

The interviews in Seoul suggested that the responsibility for air-quality monitoring and management is largely associated with the legal duty and accountability of the governments. According to the responses, the local authority has the awareness and willingness to improve the air quality, as well as the resources (power) to monitor and manage air quality legitimately (influence). Nevertheless, the responsibility is distributed to multiple administrations at different levels. For example, the funding to implement the air quality plan comes from the national government as well as the metropolitan government, and it requires collaboration with financial departments. With respect to the general public, the citizens do not have any duty to monitor air quality and interviewees suggested that the public is not aware of its contribution to local air pollution. As such, positively influencing air pollution through various initiatives from the government and environmental pressure groups remains an aspiration.

With respect to technology innovation, the data illustrated that the scope for the installation of additional air-quality monitoring-network or information provision platform in Seoul is finite. Due to the relatively poor technical performance of current sensing techniques compared to the reference methods and the financial and manpower investment required to establish new monitoring practices, the use of new technologies was viewed as illegitimate and infeasible for regulatory monitoring. Given the publicly available and well accessible air quality information in Seoul, generating extra data and getting information on additional platforms through voluntary new monitoring systems seems to be dispensable. Still, the participants noted that these technologies could be used in scientific studies to inform policy in the long-run (progress). For instance, such extra data could help researchers to map the transport and formation of atmospheric pollutants and the impacts of personal exposure on human health. Also, the data generated can be used as part of urban big data to provide individualised information, especially for vulnerable people. Even so, the participants suggested that the responsibility in the process, for example, the communication network design, big data collection and data sharing, needs to be clarified.

To summarise, the grounded theory themes are also applicable to the megacity of Seoul. The concept of Awareness and Willingness remains as the core and the relations between each of the themes are consistent. Nonetheless, the contents of two themes required certain refinement. The modifications were made to the central theme of Awareness and Willingness as well as to the theme of Power and Influence.

For the central theme, the results of Seoul further emphasised that the identification and understanding of varying barriers to air pollution abatement are critical to effective management of local air quality. The challenges of addressing air pollution include not only environmental institutions and material resources, but also related administrations within the government need to have a good level of awareness regarding their self-responsibility, and the willingness to take actions. As such, environmental authorities have been able to take targeted actions. Therefore, the issue concerning the awareness of barriers in local air quality management was added to the core theme.

Meanwhile, the thematic analysis indicated that issues concerning the collaboration between different administrations at all levels of the government, as well as the relationships between various stakeholders and between nearby countries are critical to the management of local air quality. The matters of collaboration and relationships are important as emission sources are a mixture of domestic and transported contributions. The sources of pollutants also come from a wide range of sectors. For reducing the concentrations of PM2.5 in particular, in depth collaboration and cooperation with other administrations of the national governments and with international stakeholders are essential. Hence, the content of the theme of Power and Influence was updated with additional subjects of collaboration and relationships.

Moreover, the relations between responsibility and technological innovation were updated by adding the subject of data sharing. Data sharing elaborates the possible role of big data in air quality monitoring in addition to its use in data management and quality control. The topic of big data was of interest to the air quality management of Seoul city as the information infrastructure of the city is well established. Introducing an additional communication network would however require clarification of the responsibilities held by different stakeholders.

The updated theme descriptions are detailed in the following Table 6- 2.

Table 6- 2 Theme description and updates (Seoul)

Theme	Summary for York and Berlin analysis	Summary for Seoul analysis
State and progress	• Policy development and progress of the air quality agenda • Emission control policies (especially transportation) • Political system and organisations with respect to the monitoring and management of air quality • Perceptions of the development of monitoring techniques • Use of generated air quality data and information provision	
Awareness and willingness	• Knowledge of the availability of air quality information channel and how that information is perceived • Understanding the adverse impacts of air pollution and willingness to change behaviour • Policy priority and political will to tackle air pollution • Awareness of self-responsibility	• Awareness of administrative and social barriers
Power and influence	• Possession of resources which are needed to establish air-quality monitoring practice and implement control measures • Legitimacy and political influence with respect to local air quality management • Development and challenges in terms of taking up new monitoring technologies • How the impacts of non-regulatory monitoring are perceived and what interests do end-user stakeholders have	• Engagement in cross-government and intergovernmental collaboration
Responsibility	• Possession of resources which are needed to monitor and/or improve air quality • Distribution of impacts and accountability of the management organisation • Scales of responsibility due to the impacts of air pollution (for example, local or national, personal) • Types of responsibility (legal or ethical) • Distribution of responsibility for data management	
Technological innovation	• Availability and features of non-regulatory air quality sensing technique • Concerns about the challenges of the innovation • Potential functions, cost and benefits • Forms of information provision	

6.5 Chapter conclusion

This chapter presented the analysis of the qualitative data gathered in Seoul. As such this research identified the complexity of air-quality monitoring and management in a populous Asian city. The analysis showed that the themes that emerged from the York and Berlin case studies were equally applicable to the Seoul case, i.e., 1) state and progress; 2) awareness and willingness; 3) power and influence; 4) responsibility; and 5) technological innovation. Two themes were however updated by adding sub-concepts as a result of the accumulation of the coding at the end of the analysis.

First, the findings show that the awareness of administrative and social barriers is a critical aspect for establishing a joint response from government and civil society groups to address air pollution. The previous responses in York and Berlin largely focused on issues related to public awareness-raising and establishing political will, less on promoting public willingness once the awareness level is satisfied. The findings from Seoul suggest that being aware of the challenges for political initiations as well as for the behavioural change are equally important.

The content of *power and influence* was modified as well. According to the interviewed responses of Seoul, the city's air quality management requires the support from several different departments locally and nationally. Moreover, transboundary emissions affect the Seoul's atmospheric status substantially. It is, therefore, crucial for the municipal administration to collaborate with relevant authorities domestically and internationally. This cooperation is particularly important for Seoul due to the size and location of the country.

The following chapter connects the thematic analysis of three cities and focuses on the interpretation of the results in relation to the end-user stakeholder concept outlined in Chapter Two.

Chapter Seven Discussion

7.0 Introduction

This chapter relates the analyses of three case study cities to the literature on end-users and stakeholders. It critically discusses the thematic concepts in relation to the end-user stakeholder concept developed in Chapter Two and the existing literature on urban air-quality monitoring and management.

Section 7.1 expands the discussion of each theme and links the findings across the three different urban settings. It discusses the interview findings and presents the factors influencing air-quality monitoring and its role in ambient air quality management. Each of the themes is reviewed and contextualised in relation to the relevant literatures. Due to the interdisciplinary nature of the research and the grounded theory approach adopted this section draws upon diverse disciplines to explain concepts that emerged from the data. The findings of each theme are largely compatible with the existing literature. Yet, by connecting the conceptual themes at the end, this account emphasises the overall significance of contextualising air-quality monitoring and explains how different monitoring practices may affect the progress of air-quality improvement. The transnational research design that underpins the thesis means that it makes empirical and methodological contributions to the interdisciplinary field of innovative air quality monitoring by applying social science methods to analyse the data collected in three different cities located in different states.

In section 7.2 the thematic concepts are related to the literature on stakeholder theory and the conceptualisation of an end-user stakeholder framework. This section provides a critical reflection upon the conceptualisation of the 'end-user stakeholder' and discusses the way in which the concept can be amended in the light of the empirical findings, specifically, the ways air quality are monitored and the ways in which data can be used are related to specific groups of end users. In doing so this study is able to highlight the function of air-quality measurements, the differences between routine and non-regulatory purposes, as well as the needs of various end-user stakeholders. By linking the variety of monitoring practices with the potential effects on air quality management, I argue that air-quality monitoring is a multi-functional societal practice that extends beyond compliance checking depending on the needs of end users. The use of innovative low-cost monitoring approaches, in particular, could fit multiple purposes for air quality improvements and scientific research.

Finally, the results of the chapter are summarised in section 7.3.

7.1 Narrative of the thematic concepts

This study employed qualitative data from three different cities and five themes were developed following analysis of the stakeholder interviews: 1) awareness and willingness, 2) state and progress, 3) power and influence, 4) responsibility and 5) technological innovation. The following diagram summarises the thematic concepts and how they are connected. The theme details are listed in Appendix VII.

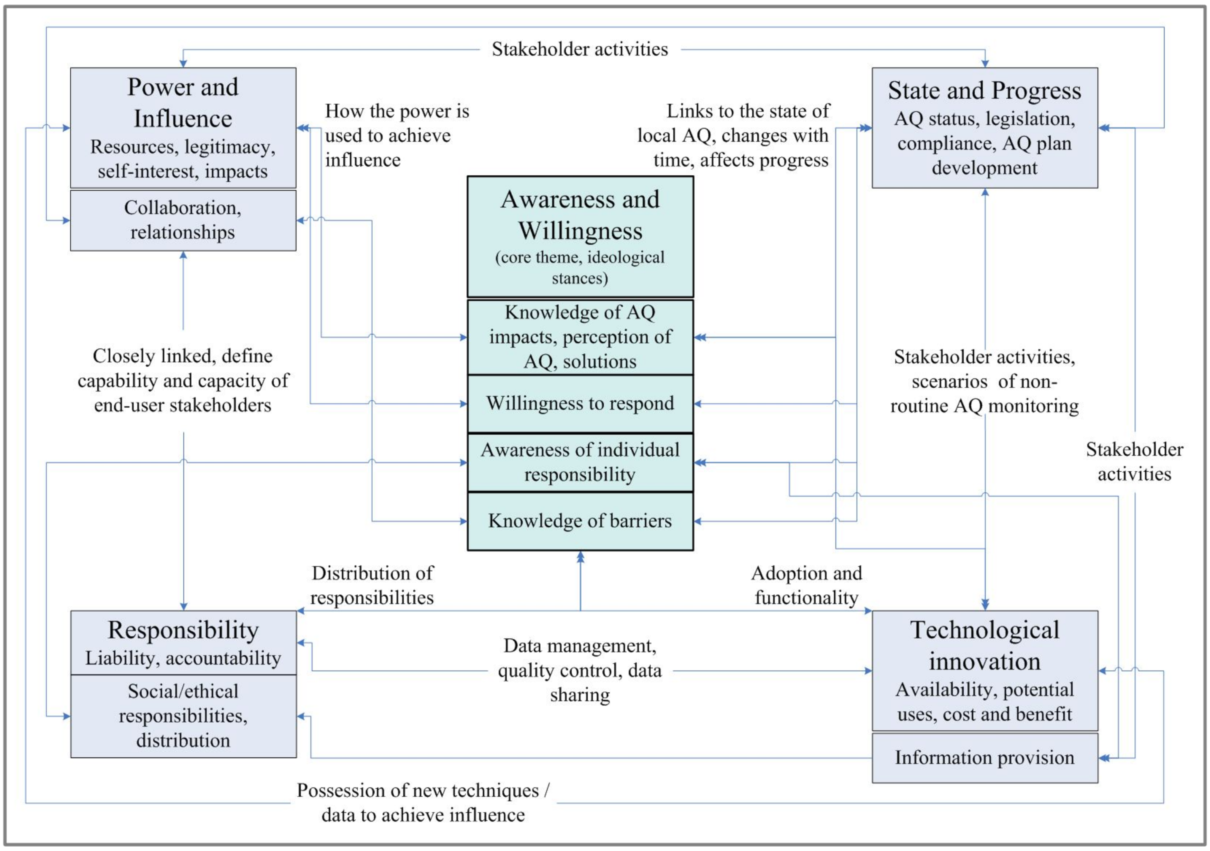

Figure 7- 1 Relations between the developed grounded theory themes as a result of the empirical investigation in York (UK), Berlin (Germany) and Seoul (South Korea)

7.1.1 Core theme: awareness and willingness

The theme of Awareness and Willingness emerged from the data as a core factor linking and underpinning the other concepts. It includes two associated subjects, *awareness* and *willingness*. Each of the subjects, i.e., awareness and willingness, differentiates between the perspective of the government and civil society. In this study, the government aspect involved the viewpoints of civil servants of local government administrations as well as local and national politicians. Civil society consists mainly of non-governmental organisations, interest groups and the general public, and is distinct from the government and industry (emitters and technology providers). Both municipal government and civil society were identified as end-user stakeholders of air-quality monitoring data in cities (see Chapter Two). This theme reveals that the understanding of air pollution, i.e., what it is and how bad it is, held by local government and local people largely affects their interests in issues related to local air pollution, such as policy interventions and NGO initiatives. Consequently, their interpretation of air quality defines how they value the deployment of new monitoring techniques, methods of disseminating air quality information, and implementation of control measures such as restrictive transport management.

Public awareness and willingness captures the perceptions, attitudes and the behavioural responses of the public to air pollution, are key themes of the literature on environmental risk perception and environmental psychology (Groot, 1967; Bickerstaff and Walker, 2001; Bickerstaff and Walker, 2003; Yearley et al., 2003; Semenza et al., 2008). Previous studies show that public awareness of air pollution, how local citizens perceive air quality, and their participation in decision-making are vital to effective policy implementation (Elliott et al., 1999; Bickerstaff and Walker, 2001; Semenza et al., 2008; Ngo et al., 2017). Yet, the level of awareness of air pollution and the health implications or availability of accessing understandable air quality information is limited (McDonald et al., 2002). The findings across the three cities in this study reinforce this finding in the wider literature. A common view among the respondents in York and Berlin was that there is insufficient public awareness of air pollution and its health impacts in the two European cities. Interviewed stakeholders suggested that this lack of awareness amongst the general public in York and Berlin reduced the level of political will to make extra efforts in monitoring and implementing pollution control policies, especially with respect to traffic management. Lack of awareness also increased political worries about public reaction to restrictive traffic policies, as in the case of the closure of Lendal Bridge in York. The failed trial traffic ban attracted significant public attention and critical responses, which appears to have dampened the political will for similar policy interventions (see Chapter Four).

In contrast to the two European cities, the interviewees from Seoul reported that a majority of the residents of Seoul are aware of air pollution. The York and Berlin findings suggested that policy-makers believe that an increase in knowledge and awareness would lead to wider acceptance of new policy interventions and likelihood of behaviour change. If this were true, then we might expect public willingness to change behaviour to be higher in Seoul based on a relatively higher level of public awareness. However, interviewees from Seoul implied that the perception of the issue, and its adverse health implications, do not necessarily translate into a high level of willingness to change individual lifestyle to improve poor air quality. Thus, there appears to be a gap between the concern (awareness) and support for governmental initiatives and changes in life style (willingness), for instance reducing car use. This is recognised in the literature about the valuation of air pollution (Carlsson and Johansson-Stenman, 2000) and public willingness to pay for environmental friendly products in environmental economic studies (Royne et al., 2011). In general, the interviewees from York and Berlin suggested that being unaware of air pollution limits people's positive responses. But even when poor air quality and its impacts are recognised by local citizens and a substantial concern emerges, there may still be an unwillingness to do anything that would affect the convenience of daily life. Environmental concern has to compete with other interests particularly the freedom of using private vehicles.

As for the levels of awareness and willingness of government, the interviews suggested that there is a distinction between the perspective of civil servants (administration) and that of the politicians (policy-making). These findings reflect work in the public administration literature. For example, in a public choice study, Schneider and Volkert (1999) mention that due to the interactions with various players involved in environmental policies, local and national environmental bureaucracies often have a superior knowledge of environment issues. The interviewee responses confirmed Schneider's finding, suggesting that the staff working in air quality administration enjoy higher levels of knowledge about air pollution. However, the awareness at administrative level does not necessarily shape that of the politicians in decision making. Instead, my data suggested that public concern is of great importance in introducing additional measures in air quality management, i.e., making efforts to extend monitoring beyond legal requirements. The findings in Seoul, in particular, indicated that the national and local authorities have been increasingly willing to broaden citizen participation in air quality management. This change is in part as a response to increased recognition of the role of public attitudes and responses to air pollution. The findings of York and Berlin revealed that there is a belief among end-user stakeholders that higher public awareness of air quality could positively influence how local government considers policy instruments oriented to air quality improvement. For example, the view is presented that when public concerns are raised, local policymakers may prioritise the allocation of funding and manpower for monitoring and dissemination of air quality information, as well as the arrangement of economic incentives for cleaner vehicles and planning emission control areas. The findings are in accordance with previous analyses confirming that public involvement is a fundamental element of the democratic institutions and that it affects the evaluation of policymakers regarding trade-offs of different topics in an election (e.g. Schneider and Volkert, 1999; Smith, 2003; Petts and Brooks, 2006; Dryzek and Stevenson, 2011).

The influence of public viewpoints is not only relevant to politicians in a representative political institution, but also acts at the administrative level. The findings across the cities indicated that current air-quality monitoring and information provision is deemed an administrative duty, which, unlike traffic management, causes less political debate. This seems to be the case especially in Berlin where interviewees suggested that the public administration has a significant role in setting and managing environmental regulations, for example, the federal environmental agency UBA and the air quality bureau of the Senate of Berlin.

Given the above evidence, questions remain about how to affect public awareness and willingness and how to motivate the public to change its behaviour. While the findings of this research suggest that public knowledge does not necessarily translate into behaviour change, other environmental valuation studies show that air pollution reduces life satisfaction and individual well-being (Luechinger, 2009; MacKerron and Mourato, 2009; Ferreira et al., 2013). In such cases, public awareness is essential for evaluating the social value of air quality as it contributes to the definition of the issue, defines appropriate attributions of blame, and identifies corresponding behaviours. These are important elements for considering the role of air quality measurements as well as processed information. They are largely related to the status of air pollution monitoring and management (state and progress), the involvement of end-user stakeholders (power and influence as well as responsibility), and also the availability of monitoring techniques (technological innovation).

7.1.2 State and progress

This theme revealed the contextual background of air-quality monitoring in each of the case study cities. It captured the current status of air quality, monitoring network and information provision in each city (state), as well as the changes in levels of atmospheric pollutants and related policies (progress). As such, the theme reflects the development of air quality as an issue and the efficacy of ambient air quality management in cities.

Bickerstaff and Walker (2001) in the review of the air pollution perception literature concluded that public understanding of the environment is affected by local levels of pollution and the publication of air quality information. Earlier studies concluded that visibility reduction is caused by elevated levels of aerosols in the atmosphere (Dzubay et al., 1982; Kim et al., 2006; Seinfeld and Pandis, 2016). Particles can be directly produced from emission sources or indirectly generated through secondary formation due to the conversion of volatile organic compounds and often have a connection with risks to human health (Davidson et al., 2005; Seinfeld and Pandis, 2016). Yet, particulate matter is a complex mixture of particles in various sizes and chemical compositions. The source apportionment is, therefore, important for identifying the sources and enacting corresponding control measures. Previous studies of emission sources of PM show that long-range transboundary pollution has a strong influence on particulate concentrations in South Korea (Lee et al., 2001; Lee et al., 2011; Lee et al., 2013). The findings of this study show that the transported pollutants are noticed by not only the experts but also the general public (public awareness), largely due to reduced visibility, especially in the winter season. As for York and Berlin, where PM levels are relatively well managed, the fact that the local pollution is 'not visible' was identified by interviewees as one of the barriers affecting how citizens perceive and prioritise the issue.

In addition to impaired visibility, the findings support the conclusions of Bickerstaff and Walker (2001) and McDonald et al. (2002), suggesting that the conditions of public air quality information provision have an effect on citizens' awareness of and interest in air quality issues. In Seoul, information on air pollution and advice on how to respond to poor air quality are made available through a range of channels. The platforms involve designated official websites - on which people are able to retrieve detailed information, television and radio broadcasting. The information is also disseminated as mobile text messages which require little effort on the part of the recipients. Thus, air quality information is embedded in the context of citizens' everyday life. In York and Berlin, although more detailed information is available at the national level, there was limited information on the websites of the local authorities at the time of data collection. Even here, however, readers need to have some knowledge about air quality measurements and related terminology in order to assimilate the information. That is because the information was provided in a format that is less readily understandable to the general public. The unsatisfactory information infrastructure and content was deemed by interviewees to be another obstacle inhibiting the public's understanding and motivation to address local air pollution. By conducting social surveys, Beaumont et al. (1999) and Bush et al. (2001) showed earlier that local authorities in the UK failed to provide meaningful air quality knowledge locally, and that what was made available was not useful to different user groups. This study suggested that there were limited improvements in local information infrastructure while the research interviews in York and Berlin were being carried out[43]. Some of the reasons for this slow progress relate to capacity and the broader duties of local governments, which emerged under the thematic headings of power and influence, and responsibility.

Another important issue arising under the heading of '*state and progress*' concerned the legal requirements for ambient air quality. The two European cities are required to comply with the limit values set in the EU's Air Quality Directive.[44] Air-quality monitoring methods and data exchange

[43] The researcher is aware that new air quality websites are available in York and Berlin. However, these websites were published after the fieldwork. Taking these platforms into account, therefore, is beyond the research scope.
[44] At the time of this research, EU laws are still applicable to the UK.

procedures are harmonised through these measures so that the data can be compared and evaluated across EU member states. According to the measurements of local authorities, NO_2 is the main pollutant exceeding the limit values in both York and Berlin (BBC News, 2014; City of York Council, 2016a; Senate Department for Urban Development and the Environment, 2014). In addition to NO_2, PM10 levels are exceeded on main roads in Berlin (Senate Department for Urban Development and the Environment, 2014). Meanwhile, particle levels, PM2.5 in particular, are the key policy concern in Seoul (Seoul Metropolitan Government, 2015d; Seoul Metropolitan Government, 2017c). These breaches are evaluated based on the legal requirements of the EU and that of South Korea. In the EU's Air Quality Directive, these legal values are called '*limit values*' (Council Directive, 2008), whereas, in South Korea, they are referred to as '*ambient air quality standards*' (Ministry of Environment, 2015c). Yet, as there are no supranational legal standards for ambient air quality, '*exceedances*' can and do represent different levels of pollution. The EU limit value for PM10 is 50 $\mu g/m^3$ on a 24 hour-averaging time (i.e., daily) which should not exceed more than 35 days in one calendar year, and the annual average value is 40 $\mu g/m^3$ (Council Directive, 2008). The daily threshold for NO_2 is 200 $\mu g/m^3$ (permitted exceedances must not be more than 18 times a year) and the annual limit value is 40 $\mu g/m^3$ (ibid.). In South Korea, these are regulated as not more than 100 $\mu g/m^3$ daily and 50 $\mu g/m^3$ annually for PM10, and not more than 0.1 ppm (188 $\mu g/m^3$) hourly, 0.06 ppm (112.8 $\mu g/m^3$) daily, and 0.03 ppm (56.4 $\mu g/m^3$) annually for NO_2[45]. As for PM2.5, although there are EU limit values and national reduction targets for background concentrations at each member state, the value is an annual average and the reduction objectives are implemented at national level but not implemented as a requirement for local authorities to meet (Council Directive, 2008; Senate Department for Urban Development and the Environment, 2014; City of York Council, 2016a). Instead, PM2.5 national standards are measured daily and annually which are also enforceable in Seoul (Ministry of Environment, 2015c). This may explain why NO_2 is emphasized in air quality policies in the two European cities but not PM, especially not PM2.5.

[45] 1ppb = 1.88 $\mu g/m^3$, this conversion is calculated at an ambient pressure of 1 atmosphere and a temperature of 25 degrees Celsius for NO_2.

Additionally, the air quality standards for PM in the three countries are all higher than the WHO air quality guideline values. The divergence is widely noticed in the environment and public health literature. Vahlsing and Smith (2012) reviewed short-term national air quality standards for PM10 in 96 countries and concluded that most of the countries have higher standards than the WHO air quality guideline values[46]. More recently, Joss et al. (2017) conducted a systematic inventory to review ambient air quality standards worldwide for different averaging times and concluded that substantial heterogeneity exists globally depending on the pollutant and the country. As for PM and NO_2, the agreement of PM standards with WHO guideline values is lower (Joss et al., 2017). This is also true in the EU and South Korean thresholds. Although the EU Air Quality Directive is among the strictest globally (Wolff and Perry, 2010), the PM2.5 and PM10 standards are still higher than science-based WHO guideline values, therefore they are '*far too high*', as Brunekreef et al. (2015) commented on the EU limit values. The annual mean values of WHO guidelines for PM10 and PM2.5 are 20 μg/m^3 and 10 μg/m^3, respectively (WHO, 2006). The EU annual limit values are at least two times higher than the WHO recommendations: 40 μg/m^3 for PM10 and 25 μg/m^3 for PM2.5, but there is no short-term standard for PM2.5 (Council Directive, 2008). While in South Korea, the annual standards are 50 μg/m^3 and 25 μg/m^3, respectively. The 24-hour average is two times higher than the WHO guideline value (Ministry of Environment, 2015c). The different air quality regulatory values and WHO recommended guidelines are listed in Table 7- 1.

Although PM targets are all higher than the guideline values, for the annual mean in particular, they are within the interim targets (IT) (WHO, 2006). These interim targets are set as 'incremental steps' towards the reduction of PM levels, and the attainment of these values would result in a significant reduction in health risk. For the EU, the annual PM10 average is between the IT-2 (50 μg/m^3) and IT-3 (30 μg/m^3), and PM2.5 annual mean meets the IT-2 value of 25 μg/m^3, as for South Korea, both PM10 and PM2.5 are the same as WHO interim target 2 (IT-2) (ibid.).

[46] The study also included SO_2 standards.

Table 7- 1 Air quality standards for NO_2 and PM in EU and South Korea, and WHO air quality guidelines (Council Directive, 2008, Ministry of Environment, 2015c, WHO, 2006)

Pollutant	Averaging period	Concentrations		
		EU	South Korea	WHO guidelines
NO_2	1 hour	200 μg/m^{3a}	0.1 ppm (188 μg/m^3)	200 μg/m3
	24 hours		0.06 ppm (112.8 μg/m^3)	
	1 year	40 μg/m^3	0.03 ppm (56.4 μg/m^3)	40 μg/m3
PM10	24 hours	50 μg/m^{3b}	100 μg/m^3	50 μg/m^3
	1 year	40 μg/m^3	50 μg/m^3	20 μg/m^3
PM2.5	24 hours		50 μg/m^3	25 μg/m^3
	1 year	25 μg/m^3	25 μg/m^3 (target value of Seoul 20 μg/m^3)	10 μg/m^3

a. Not to be exceeded more than 18 times per calendar year

b. Not to be exceeded more than 35 times per calendar year

The discrepancy in air quality standards between national air quality standards and WHO guideline values, and between those of the EU and South Korea, reflects the gap between science and policy implementation and the diversity of air pollution issues in the EU and South Korea. The WHO recommendations only consider scientific evidence driven by public health concerns - and not other factors, such as technological feasibility, economic, political and social aspects - for achieving such recommended reference levels (European Parliament, 2014; Joss et al., 2017). Thus, legal requirements in practice could be much higher than WHO guidelines per region per country (as shown in Table 7- 1 in this dissertation).

Furthermore, the discrepancy between different pollutants relates to the expectation of feasibility of addressing diverse emission sources. For the most concerning atmospheric pollutants in this study, road transport is a major source of NOx and primary PM emissions in urban areas. With respect to NOx in particular, it is the largest emission source and responsible for NO_2 exceedances in many cities of the EU-28, including York and Berlin (see Chapter Four, Five and earlier in this theme).

One explanatory factor for NO_2 breaches is the pace of dieselisation and performance of diesel engines in Europe. At the EU level a drive to reduce carbon emissions, resulted in many member states introducing financial incentives to encourage the take-up of diesel-powered vehicles based on lower CO_2 emissions (EEA, 2015). As a result, the European vehicle fleet has experienced an increasing dieselisation since the early 2000s, especially among commercial vehicles[47] (European Commission, 1998, EEA, 2015, ACEA, 2017). With the development of engine technologies and tightened tailpipe regulations (i.e., Euro emission standards) and transport management policies (e.g., Low Emission Zone in Berlin), both NOx and PM emissions have declined in Europe. Statistics show that between 1990 and 2015, NOx emissions from road transport reduced by 60% (EEA, 2015). Between 2000 and 2015, PM10 emissions from road transport reduced by 40% and 50% for PM2.5[48] (Figure 7- 2). Traffic-related emissions would continue to decrease if stringent Euro standards are met. However, the diesel fleet continues to grow. Meanwhile, disparities between vehicle type approval for checking compliance with the Euro exhaust emission standards and real-world driving emissions are increasing. The two reasons together technically make the attainment of limit values more difficult in the European context (European Parliament, 2014; EEA, 2015).

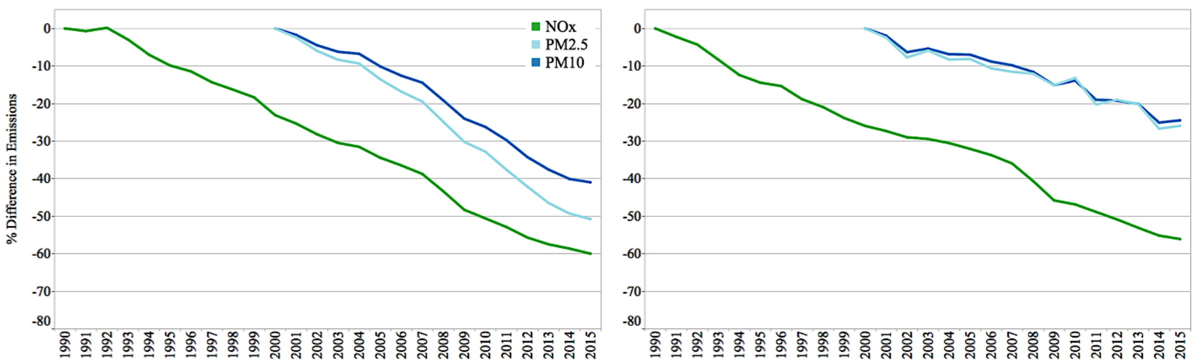

Figure 7- 2 EU-28 emission trends in road transport (L) and national total (R) for NOx, PM2.5 and PM10 between 1990 (2000) and 2015, modified based on (EEA, 2017a).

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[47] Commercial vehicles include light commercial vehicles (a gross vehicle weight of not more than 3 500 kg), medium and heavy commercial vehicles (a gross vehicle weight above 3 500 kg) (ACEA, 2017). In 2015, 89% of the commercial vehicle fleet in the EU had diesel engines. Almost all heavy goods vehicles on road were diesel (95.5%). The percentage of diesel passenger cars in the total car fleet was 41%. In total, 47% of road vehicles in the EU were diesel, the figures were 44% in the UK and 37% in Germany. As for passenger cars, the shares of diesel in the UK and Germany were 37% and 32%, respectively. Calculations are based on European Automobile Manufacturers' Association Report, it should be noted that the datasets do not include data of Bulgaria, Cyprus and Malta in the EU-28 (ibid.).

[48] According to reporting obligations, PM10 and PM2.5 data are available since 2000 (EEA, 2017c).

Reductions of PM concentrations require effective control of a broad spectrum of both primary and secondary sources (due to chemical reactions of gaseous precursors, for instance, emissions of NOx). Such sources can be domestic (e.g., road traffic, domestic heating, wood burning, industries, agriculture), and can also be long range (e.g. Saharan dust) (WHO, 2006, European Parliament, 2014, Harrison et al., 2014). As such, despite the reductions in the sector of road transportation, the decline in total PM emissions was not as substantial as that of NOx (see Figure 7- 2). Even existing control measures for road transportation have had a limited influence on PM as non-exhaust emissions, such as tyre and brake wear, and road abrasion, are not regulated by Euro emission standards (EEA, 2017b).

While Seoul has experienced similar changes in the proportions of on-road diesel vehicles, the narrative about the relationship between dieselisation and air quality policies is different. Accompanied by the country's economic growth, the number of vehicles has increased significantly, i.e., it rose by 67% over the period of 2000-2014 (Dong and Lee, 2017). Consequently, road transport is a major domestic source of South Korean air pollution. In 2014, nearly 45% of all vehicles in the country were concentrated in the capital area, with 15% in Seoul. The share of diesel-powered vehicles in the city increased from 22% in 2000 to 33% in 2014 due to better fuel economy when compared to petrol vehicles (ibid.).[49] In order to reduce road transport emissions, both the national government and the Seoul city government introduced a series of policies to encourage the use of low-emission vehicles. In 2000, the Seoul Metropolitan Government implemented a low emissions programme (Seoul Metropolitan Government, 2015d). The timeline was associated with the 2002 World Cup with specific action plans applied before and after the event (ibid.). Further, with the introduction of the Special Act on the Improvement of Air and Environment for the Seoul Metropolitan Area at the end of 2003 and its first national policy strategy and municipal master plan in 2005, the national and local governments located a budget of KRW 4 trillion (3.7 billion USD)[50] to improve regional air quality (Seoul Metropolitan Government, 2015d;

[49] The same report stated that the share of diesel vehicles in South Korea is higher than other countries, saying: 'In other countries, such as the United States, Japan, and Germany, diesel vehicles account for only 3%, 13%, and 18% of all vehicles, respectively.' Although details of the figure are not available, according to the data derived from ACEA, this is not the case for Germany, even passenger car accounted for 32% in 2015, which was lower than that of commercial vehicles.

[50] 1 US Dollar is 1070 South Korean Won, based on average exchange rate in the period of 1 January to 7 April 2018. Source: OANDA exchange rates (www.oanda.com/fx-for-business/historical-rates)

Dong and Lee, 2017). 90% of the budget was arranged for addressing emissions from diesel vehicles over the period of 2005-2014, particularly city buses and medium and heavy goods vehicles (ibid.). The aim was to improve the visibility of the area so that the Incheon coastline would be visible from the Namsan Mountain in Seoul on a clear day. In terms of pollutants, the targets were to reduce PM10 and NO_2 concentrations to the average levels of OECD cities, 40 μg/m^3 and 22 ppb[51], respectively (Seoul Metropolitan Government, 2015d). Both of the objectives were stricter than the national air quality standards and almost the same as the EU limit values (see Table 7- 1). By implementing numerous incentives and subsidies, the diesel bus fleet of Seoul was replaced by CNG buses[52] and 265,591 diesel vehicles were covered by the low emission programme by the end of 2013. However, the reduction objectives were not achieved at the end of the first action plan (Seoul Metropolitan Government, 2015d, Dong and Lee, 2017). The second ten-year action plan was scheduled to start in 2015, which focused on human health protection. It set a goal to reduce the PM2.5 level to 20 μg/m3, PM10 to 30 μg/m^3, and NO_2 to 21 ppb (Jong In Don and Sang Gu Yeo, 2017). At the municipal level, the policy objective is even more ambitious (i.e., a high level of political willingness), which strived to achieve a 20% reduction of PM2.5 in four-year's time, cutting the annual level to 20 μg/m^3 by 2018 (Seoul Metropolitan Government, 2017a; Seoul Metropolitan Government, 2017c,). Yet, the emphasis on particulates, PM2.5 in particular, in both national and municipal policy objectives, reflects that the health impacts of NO_2 have not yet received adequate political attention, as it often implied as one of the precursors of PM only, for instance, '*(NO_2) is the major source of ultrafine particles*' (Seoul Metropolitan Government, 2015c).

Nonetheless, as the WHO (2006) stated, '*no truly safe level of exposure*' has been found. Thus, reporting the results of compliance monitoring only can be incomplete and misleading as it implies that the health risk would be avoided if these standard levels are achieved. Therefore, this study argues that the acknowledgement of and methods to recognise the importance of continuous reduction of air pollution exposure are important to both decision makers and the general public. Yet how can this shift in people's

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[51] They are the standards of Tokyo (PM10) and Paris (NO_2).

[52] The initiative of switching city buses to CNG was also a response to the increasing oil price since 2000 (Seoul Metropolitan Government, 2015d).

understanding of air pollution levels be achieved? How are end-user stakeholders involved in the process and what are the impacts? The following themes detail the roles of the government and civil society, as well as the possibilities of deploying new air-quality monitoring practice to supplement regulatory monitoring.

7.1.3 Power and influence

This theme captured the possession of power and when and how it is exercised. While power refers to the resources required in urban air-quality monitoring and management, the term influence signifies the potential benefits of enacting activities. There are a range of resources, such as material, legal and cultural, which together justify the capacities and interests of end-user stakeholders in local air-quality monitoring and management.

First, operating air-quality monitoring-networks and providing reliable information are important administrative duties of government. As such, regulatory authorities are able to use measurements to evaluate atmospheric pollutants in specific areas and further develop policies regarding air quality management (Larssen et al., 1999, WHO, 2006). Environmental institutions, such as Defra in the UK, UBA in Germany, NIER in South Korea, as well as local air quality divisions under local governments, are the designated administrative bodies that hold legal power and resources to operate regulatory monitoring networks. However, compliance monitoring is only part of air quality management. Achieving air pollution abatement is characterised by high complexity, involving a series of activities and collaboration with different bodies within the government. Larssen et al. (1999) illustrate the relation between air quality measurements and other activities in air quality management and specified that the objective of compliance monitoring is defined by legislation in the European context (Figure 7- 3).

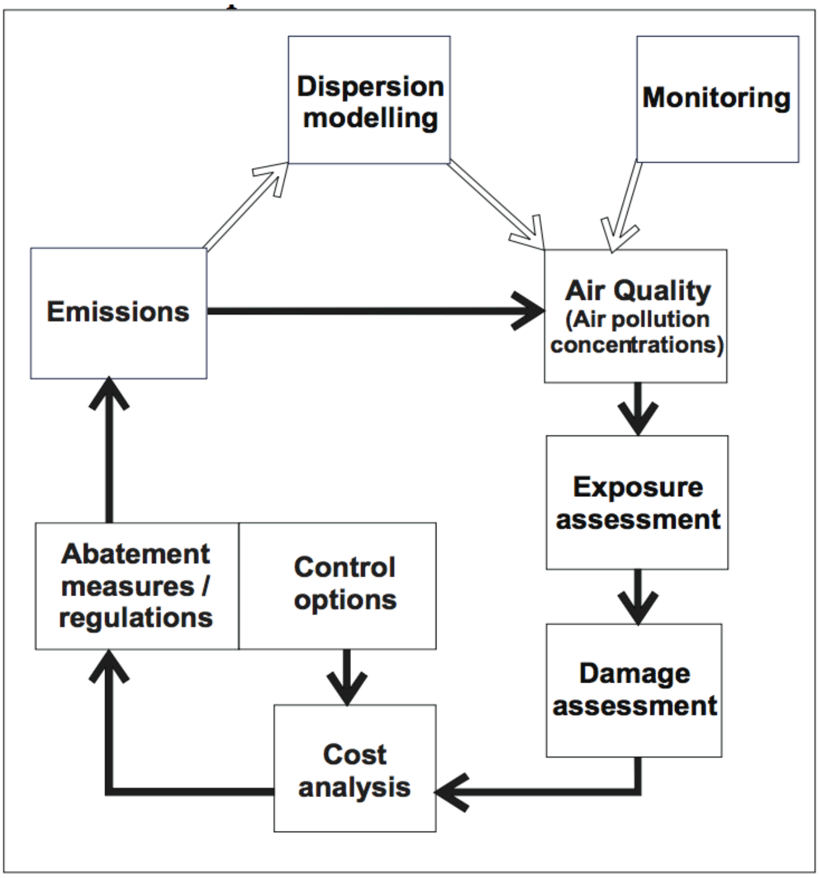

Figure 7- 3 Analytical process of air quality management in European context (Larssen et al., 1999)

However, fragmented governance is a challenge in managing environmental problems, especially global issues such as climate change and trans-boundary air pollution (Lafferty, 2003; Biermann et al., 2009; Zelli and Van Asselt, 2013). Environmental authorities often have limited influence on other departments that are responsible for other activities that may contribute to air pollution due to the institutional segmentation of administrative systems (Lafferty, 2003; Carter, 2007; Jordan and Lenschow, 2010). For example, agricultural, transport, and energy departments are important economic ministries. Policy decisions of these economic sectors often involve activities that affect the environment. However, each individual ministry has specific responsibilities and policy objectives which may not sufficiently involve environmental considerations (Lafferty, 2003; Carter, 2007). This is particularly challenging when financial and human resources are limited as political concerns and prioritisation of local issues would be affected by economic conditions. Such impacts are also found in different fields, such as the literature of urban political ecology (Véron, 2006), sustainability transitions (Geels, 2013) and environmental planning and management (Barnes et al., 2014). Gibbs et al. (2002)

describe in the study of economy–environment relations that local sustainability objectives often conflict with economic development. Efforts towards sustainability to a large extent are driven by external regulatory pressure, for example, the national air quality targets and EU Air Quality Directive (ibid.). The empirical findings of this project also reflected that environmental administrators are constrained by the local fiscal situation and the responsibilities of other departments. In York, the scope of the regulatory air-quality monitoring-network, and the number of diffusion tubes, in particular, has been affected by the budget savings of the council. The Berlin results indicated that anticipated expenditures on reducing emissions from traffic have an impact on air quality management. The evidence from Seoul shows that cost is one of the barriers affecting the adoption of new monitoring techniques as well as implementing remedial measures. This finding is emerging in other studies of the impact of the economic crisis on environmental policymaking (Geels, 2013; Burns et al., 2019). Nonetheless, all three cities attested that transport management is imperative for an effective urban air quality management, and a close collaboration between different authorities is a requisite.

In addition to the fragmentation of different functional administrations horizontally, this is also an issue relating to the relationships of local governments with the central government and their autonomy regarding local air quality policies. Among the three cities, Seoul, holds the legal status of being a 'special city'[53], and is governed directly from the central authority. Although requiring co-operation with the regional office, Seoul City has acquired autonomy to set air quality standards and enact abatement policies locally, for instance, to regulate and reform public transportation of the city (OECD, 2005; Seoul Metropolitan Government, 2015d). Berlin is both a city and a federal state of the country, ranking at a higher level among sub-national authorities in the federal government system (OECD, 2006b). The Berlin Senate has rights to legislate local affairs within the Basic Law including the local public transport system (Grundgesetz, Constitution) (OECD, 2012). Both of the cities are capitals and thereby exercise political influence due to their close proximity to major governing bodies and

[53] Article 174 of the Local Autonomy Act notes that 'Exceptions may be granted to the status, organisation, and operation of Seoul Special Metropolitan City in consideration of its distinctiveness as a capital city, as prescribed by Acts'. Local Autonomy Act, Amended by Act No. 14839, Jul. 26, 2017. Available: elaw.klri.re.kr/eng_service/lawView.do?hseq=44511&lang=ENG, accessed 9 May 2018.

jurisdictional boundaries of political systems (OECD, 2012; OECD, 2014). Whereas in England the decision-making system is more centralised compared to other OECD countries (OECD, 2006c). York, as one of the unitary authorities lies outside the Combined City Authorities and London in England[54] (Sandford, 2017), and whilst it is responsible for all public services including local environment protection and local transport, it does not receive much national attention. Even if regional institutions are established, for instance the West Yorkshire Combined Authority, they often focus upon economic prosperity (Sandford, 2016). It remains unclear what the implications of being part of the regional institution would be for air quality improvement. The findings on York revealed that the air quality management is a local issue yet local authority has limited legitimacy and resources to raise environmental issues. Interviewees felt that public engagement and national support were imperative for securing environmental gains in this context (see Chapter Four). The findings are consistent with previous studies on York air quality management (see, Yearley et al., 2003; Cinderby and Forrester, 2005; Yearley, 2006), which found that public knowledge in local air quality management could supplement official air quality data and that engagement could increase the legitimacy of local decision-making, for instance, the declaration of York Air Quality Management Areas. The analysis also agrees with the conclusions of Barnes et al. (2014), who identified four barriers affecting the effectiveness of local air quality management in the UK. Besides the resource limitations mentioned earlier, the other factors are local authority powers, intra-governmental co-operation and inter-governmental co-ordination (ibid.).

Additionally, given the transboundary nature of atmospheric pollutants, even though urban air pollution management is a local issue, it requires greater institutional arrangements not only domestically but also internationally. Unlike York and Berlin in Europe, for Seoul there is no overarching international law such as the EU Air Quality Directive, nor a central authority such as the European Commission to coordinate policy resources or to evaluate performance to ensure reduction targets are complied with. International co-operation for Seoul is, therefore, a key factor that affects the enforcement of

[54] York City Council is an associate member of the West Yorkshire combined authority, but there is no clear definition of the term. It is not used in Local Democracy, Economic Development and Construction Act 2009 nor the Cities and Local Government Devolution Act 2016 (Sandford, 2017).

international agreements and reduction of local PM levels due to the transported particles from China and Mongolia (Seoul Metropolitan Government, 2014, Seoul Metropolitan Government, 2015d).

With respect to civil society, as discussed in the previous themes, public perception to a certain extent determines political will and participation affects the enforcement of air quality abatement measures. Yet, given the fact that the individual level of awareness of and interest in air quality issues vary, the engagement of civil society is often reflected by environmental group activities and media coverage. Previous studies have shown that environmental NGOs at both the domestic and international level can be an important political force (see for example Betsill and Corell, 2001; Carter, 2007). More specifically, in the field of political economy, Binder and Neumayer (2005) conducted a systematic regression analysis to determine the relation between ENGOs strength and air pollution levels. The cross-country study concluded that the influence of ENGOs on lowering pollution concentrations is statistically significant. In another analysis, Betsill and Corell (2001) found that although the types of ENGO involvement and the subsequent influences differ, the provision of information is a powerful tool to environmental NGOs to exert influence. The results of this thesis reveal that environmental pressure groups and the media are active in increasing the profile of air pollution issues in public and political debates. The effects of influence are more obvious when the activities relate to international relations, for example, media coverage regarding international co-operation in South Korea, or enlarging national regulatory pressure, such as litigation in the UK and Germany. However, they often experience difficulties in attracting public interest locally. Such barriers have an effect on their views towards new methods of making air quality measurements and generating information.

Indeed, if air-quality monitoring and management are widely perceived to be the responsibility of governments, how can wider society be made aware of their stake in air quality management? How can people to whom such environmental issues are not of interest, be engaged? Will emerging tools and their information platforms be able to fit various end-users' purposes in practice? These questions are not only associated with the way in which current air quality, legislative and institutional contexts are perceived by different end-users, but are also related to the way that end-users understand the accountability of various parties. These issues are picked up in the discussion of the next theme. The link between new monitoring practices and different groups are further elaborated in the discussion of the theme of technological innovation.

7.1.4 Responsibility

This theme reflects the extent to which different end-user stakeholders are accountable for air pollution monitoring and management in cities. It extends the discussion on *power and influence* and addresses two further issues: the legal duties of governments and the moral obligations of citizens.

Protection of the environment and public health is a legal duty of the government, but air-quality monitoring and management responsibilities are largely concentrated within environmental ministries. Generally, environmental units at all levels of governments are accountable for urban air-quality monitoring and management. Still, as discussed previously, due to the jurisdictional boundaries of administrative systems, achieving air quality objectives may not be integrated into other policy areas. To overcome fragmentation, air quality objectives need to be viewed as a co-operative and inter-sectoral target, with co-ordination at the national level (WCED, 1987). However, the establishment of a ministry of the environment and cross-sectoral environmental agencies or attempts at environmental policy integration at the national level may have limited impact on policy delivery due to various contextual factors, such as the availability of leadership and resources (Carter, 2007; Jordan and Lenschow, 2010). The exceedances of pollution levels in the three cities of this project show that, so far, co-ordination has had a limited impact on further abatement of ambient air pollution due to the difficulties of emission control, and the fact that traffic is a major source of pollution. This challenge in turn requires us to consider the role of public participation in air quality issues, which also relate to the second part of the discussion, i.e., the responsibility of general public.

In public choice theories, air quality is one type of public good (Ostrom and Ostrom, 1977). In this regard, there is no exclusion of the ‘consumers’ of such good, i.e., all suffer the adverse health impacts when air pollution is severe, likewise, no individual can be excluded when air quality is improved. This characteristic enables people to take advantage of others without making their own efforts. For instance, some voters may free-ride on the participation process, leaving environmentally favourable decisions to others and voting for self-interested economic policies (Schneider and Volkert, 1999). In this study, the findings reveal a strong shared perception that the wider public is unconscious of their individual moral responsibility to refrain from unnecessary car use. It is also challenging for the public to share the responsibility for improving air quality and for governments to compel each individual to act. Methods for increasing public awareness of air pollution, its health risks as well as ethical obligations, are, therefore, of interest to environmental advocates.

The findings associated with this theme highlighted that the normative obligation of society and legal duty of government are both salient to urban air quality abatement. The fact that road transport is a dominant emission source of harmful atmospheric pollutants is almost uniform in urbanised areas. As such, all car users are emitters. Although vehicle emission standards exist, driving frequency and behaviour are at the discretion of vehicle users. Meantime, there is growing epidemiological evidence of air pollution and concentrations of concerned pollutants, for example, health statistics in World Health Organisation's global assessment of ambient air pollution exposure and the consequent burden of disease (WHO, 2016). Hence, this study argues that it is necessary for wider society to be aware of the environmental consequences of driving and also to made aware of other transportation options when making traveling decisions.

7.1.5 Technological innovation

This theme focuses on the perceptions of end-user stakeholders on non-traditional monitoring practice, which is the key focus of the research. Such practice mainly refers to the application of low-cost commercially available personal sensors, platforms of data and the role of such monitoring in wider urban air quality management issues. The theme addressed the analysis in the light of two facets of the monitoring objective, for compliance purpose and non-regulatory use.

Various worries exist with respect to the application of low-cost portable sensors in compliance monitoring. First, air quality measurements have to be accurate and reliable so that they can be used confidently in air quality assessment and setting policy objectives (WHO, 2006; Vahlsing and Smith, 2012). For these purposes, measurement instruments are often large, complex, expensive, stationary and prescribed in policy guidance. For example, the reference methods are prescribed in European air quality policies. In comparison, the analytical capability and long-term reliability of smaller low-cost devices are yet to be tested (Snyder et al., 2013; Lewis et al., 2016). Lewis et al. (2016) analysed the performance of 20 commonly-used low-cost sensors to measure different pollutants through laboratory experiments. The evaluation concluded that despite promising performance for some O_3 measurements, current low-cost sensors that measure PM and NO_2 either have high uncertainty or show poor data quality compared to the reference methods. Consequently, they are not capable of meeting statutory data quality objectives and do not fulfil the requirements of compliance monitoring (ibid.). The data quality generated by portable personal sensors emerged as a main concern of the interviewees, indicating the limited potential and legitimacy of these sensors for regulatory purposes.

Nonetheless, given the growing interest and public debate about air pollution, non-routine monitoring is increasingly popular. The rapid development of air-quality sensors makes measurements and access to relevant information at various locations possible (Steinle et al., 2013; Bales et al., 2014). These data can supplement existing compliance monitoring networks. For such non-compliance purposes, the requirements for accuracy of air quality data, as well as spatial and temporal representativeness of measured locations are not as rigorous as for regulatory purposes. As such, the technical performance of emerging monitoring is not necessarily as good as sophisticated routine monitoring. Castell et al. (2017) evaluated the AQMesh sensor, one of a low-cost stationary monitoring platform which is able to measure multiple pollutants including CO, NO, NO_2, O_3 and total particle counts, in both laboratory and real-world conditions. The study compared the measurements of AQMesh sensor with various monitoring objectives including awareness raising. The results of their study show that sensor performance is ambient condition-dependent. Although the sensor units performed well in laboratory tests, the field performance was less impressive. Despite that, the NO and PM10 measurements showed the application is promising in the way it can provide indicative information to citizens (ibid.). The findings of my research indicate that such indication as shown by AQMesh has a set of different possibilities. First, it can be used in research projects. Additional monitoring can help atmospheric modellers to improve modelling performance through extra sampling and benefits public health studies by collecting personal exposure data. In addition, there is a perception that as these small, portable, devices are able to demonstrate the changes in pollution level instantly and can therefore potentially be used to raise public awareness. As such, the availability of emerging monitoring tools can support environmental NGO activities, such as public engagement and lobbying policymakers. The devices can also be used in communication with emitters (including car users) as well as in environmental education. Furthermore, these sensors could provide an indicative personal choice to vulnerable people, as such protective decisions can be made. Moreover, these newly developed portable sensing practices are often supported by cloud computing platforms and wireless sensor networks, which allow users to access the information through different platforms such as smartphone applications or web-based information portal. For example, Air Quality Egg (www.airqualityegg.wickeddevice.com), OpenSense (www.opensense.ethz.ch), Citi-Sense (www.citi-sense.eu), hackAir (www.hackair.eu). As such, the users are actively involved in data generation, possibly resulting in an increased level of involvement and personal interest towards behaviour change.

From the above, the uses of monitoring practice serve different purposes for which data requirements also differ. Together with other themes, this perception of fit-for-purpose underpins the needs of end-user stakeholders. The following section updates the concept and connects the user needs with uses of air quality measurements.

7.2 End-user stakeholders and their needs

For the purposes of this study a new concept of end-user stakeholder was developed by merging insights from the literature on end-users, largely drawn from computer science and stakeholder theory in order to explore why and how different end-users may use emerging air quality monitors for cities and what impacts are on air quality management.

As discussed in Chapter Two the term end-user is widely used in computer studies which describes the human-machine interactions (Rockart and Flannery, 1983; Brancheau and Wetherbe, 1990; Pedersen et al., 2002; Lieberman et al., 2006; Ko, 2011). It is also used interchangeably as user in its broadest sense in the studies of technology development and social studies, for example Douthwaite et al. (2001) and Maclean et al. (1998). Although end-user groups can be classified and specified by applying various criteria, for instance, level of knowledge about the deployed system (McLean, 1979), or level of control of the tool (Cotterman and Kumar, 1989; Lieberman et al., 2006), the concept focuses on distinguishing people involved in technology development and the developers' counterpart, i.e., end-user. However, the term is not intended to capture the relationships between end-user groups nor the impacts of users on the adoption of developed technologies. Therefore, this research employed stakeholder theory, which is well-established and widely used in various disciplines for exploring the identity of and interactions between different stakeholders in a particular setting.

Freeman's landmark publication defined stakeholders as '*any group or individual who can affect or is affected by the achievement of the organisation's objective'* (Freeman 1984: 46, citied in Freeman, 2010). The definition has been used and extended from strategic management in business studies to a range of different fields, including public policy-making and environmental studies, for example Edelenbos and Klijn (2006), Grimble (1998), and Prell et al. (2009). Still, it is a context dependent umbrella concept, and employs system thinking. As such, stakeholder research often has a clear organisational boundary (e.g. a firm) while not involving wider contextual influence. With respect to urban air quality issues, although management is a municipal duty, regulatory, social, political, (inter)cultural factors at national and international levels need to be considered. The same is true of geographic conditions, as they affect the dispersion of atmospheric pollutants. Thus, there is no definite and universally applicable boundary of stakeholder relations regarding urban air-quality monitoring and management for cities.

This research concentrated on end-user groups of air-quality monitoring and data, who are part of a wider and complex stakeholder network. In order to extract end-users from broader stakeholders and to further explore their involvement in air-quality monitoring and management as well as their relations with air quality information, a working definition of end-user stakeholders (i.e., end-users in the study) was proposed before fieldwork:

- End-users of air-quality monitoring in city environments are people and/or organisations who eventually receive and utilise the data in activities that could guide, steer or affect social behaviours and/or actions towards cleaner air in the society. These behaviour changes and/or actions can affect urban air quality and human well-being as a whole. They are interested in environmental issues and may have certain level of power and/or influence over the development and deployment of pollution-monitoring techniques.

The definition was established drawing upon knowledge of official routine monitoring practice. It differentiates end-users of technology, end-users of data for interpretation and the ultimate recipients of processed air quality information (see Figure 2-4 in Chapter Two for the position of different end-user groups). Each of the end-user groups interacts with the monitoring device directly or indirectly. The proposed concept also considered policy makers as central end-user stakeholders.

Nevertheless, the empirical evidence gathered indicated that the concept was general and failed to specify end-users' intention of using new air-quality monitoring devices. The original idea also did not consider the relationship between various purposes of new monitoring practices and technology performance. The implied relationship between air quality knowledge and behaviour change also emerged as being misleading as the findings in the core theme showed that a good level of knowledge does not necessarily translate into responsible behaviour. Likewise, the statement that '(end-users) are interested in environmental issues' also needs to be justified as the analysis indicated that air quality information may not be of interest to the final recipients of data. In the light of these empirical findings, this research has revisited and refined the concept:

- End-users of new air-quality monitoring technologies in cities are individuals and/or organisations who are able to receive and utilise additional air quality knowledge, which is currently not available or not easily accessible through official monitoring practice.

Through analysing the data reflecting on the sketch of end-user positions in technology development (Chapter Two, Figure 2- 3), this study classified end-user stakeholder groups into two types regardless of the monitoring instrument employed. They are end-users of monitoring technology and end-users of knowledge. The first end-user group performs and manages monitoring activities. They may not further interpret or use air quality measurements. End-users of knowledge are further classified into users of data and users of information, subject to the format of the air quality data. The latter group mainly include novice users for whom explicit user-friendly information that is retrieved and refined from larger datasets is important. Such datasets can be provided by end-users of data. For example, in a crowdsourcing platform including pollution levels at locations other than that of the specific user, the information is processed and interpreted by end-users of raw data before release to information receivers. The information could also be readings of a portable device, which provides location-specific information by the technology directly without involving intermediates. This possibility is subject to the functionality of the monitoring tool. The information can also be publicly available material published by governments through various channels, e.g., website, media broadcasting, mobile notifications and messaging. End-users of data not only often have a higher level of expertise but also greater interest in air-quality issues.

Despite how end-users are involved in monitoring, end-users have a need to utilise air quality knowledge to fit their own purposes that can be for compliance checking or serve a range of non-compliance objectives. As such, the requirements for quality and the format of atmospheric measurements differ. For regulatory purposes, substances specified in air quality regulations need to be measured continuously in order to check compliance and evaluate policy initiatives. The location of such monitoring should be able to represent various urban conditions. Siting criteria, methods of monitoring, and data management are specified in official documents. Thus, for compliance purpose monitoring networks should have good performance in real-world conditions that generate high-quality measurements. End-users involved in compliance monitoring have precise needs for air quality data. With respect to non-compliance purposes, end-users' data needs are less restrictive. Therefore, they may accept different monitors with varied technical performance. For example, atmospheric scientists who want to validate a model have different data requirements from those required for activities in environmental education.

The variation of monitoring objectives and respective requirements for technology performance is related to the end-user stakeholder framework. The five interconnected concepts of the framework underpin the social and political stances of each end-user stakeholder group in air quality management (governmental and societal) and the context of potential uses of new monitoring techniques (compliance or non-compliance purposes). As such, by applying the end-user stakeholder framework, the user group and limits to the uptake of new monitoring practices can be determined. End-user stakeholder groups, their respective needs and purpose of air-quality monitoring are summarised in Table 7- 2.

Table 7- 2 End-users of and needs for air-quality monitoring.

End-user stakeholders		Purpose of monitoring	Requirement on data quality and format	End-user of conventional monitoring technology?	End-user of air quality knowledge (indirect end-user of conventional monitoring technology)		New monitoring practice favoured? (End-user of emerging monitoring technologies)
					End-user of raw data	End-user of processed information	
Government	Civil servants	Check compliance, inform policy making	Strictly following QA/QC requirements	Y	Y	Y	N, only possible for non-compliance purpose, and only when extra resource (fiscal, manpower) is available
Government	Policy maker (politicians)	Decision making (policy interventions, strategies)	Processed information by experts			Y	N
Society	Atmospheric scientists, analysts	Modelling, exposure studies	Raw data, more measurements preferred	Y (quasi-official, or government affiliation)	Y (quasi-official, or government affiliation)	Y	Y
Society	ENGOs	Awareness raising, demonstration, promoting environmental friendly lifestyle and behaviours, lobbying, environmental education	Depending on purpose and accessibility, indicative measurements acceptable			Y	Y
Society	Special interested groups (media, environment researchers, specialist public, other organisations, activist groups)	Policy analysis, reporting, awareness raising, citizen science, demonstration, increasing governments accountability, transparency	Easily accessible, understandable official information			Y	Y/N, device is optional, improved information infrastructure is of interest
Society	General public	Inform daily activity	Easily accessible, understandable information			Y	Y, improved information infrastructure is of interest

Note: Y (yes), N (No)

The main goal of this research was to establish the needs of end-users of air-quality monitoring data and to explore the implications of their uses on air quality improvements. The table (Table 7- 2), as a result of developing and applying end-user stakeholder framework in three case studies, provides useful inputs for achieving the research objective. Still, it needs to be noted that end-user stakeholders are part of a wider range of stakeholders related to urban air quality management.

By revisiting and refining the original definition of end-user stakeholder, this study identified two end-user stakeholder categories, i) governmental and ii) social, depending upon their involvement in current monitoring practice (i.e., compliance monitoring). The involvement of the first group is defined by law. Therefore, they primarily focus on routine monitoring for checking compliance and monitoring methods and outputs are prescribed. In contrast, the second end-user group is able to accommodate multiple objectives. Hence, the requirements for exact device and performance regarding data quality are context-dependent. This distinction also explains the attitudes of some interviewees towards new means of air-quality monitoring.

Furthermore, levels of skill in processing and interpreting air quality measurements vary largely among end-user groups. Civil servants, scientists, part of ENGO and special interest groups may be more skilful than other end-users. For specific purposes, such as checking air quality standards and modelling, the data requirements can be demanding. Yet, the more expert end-users are, the higher capability they may possess for managing different datasets from diverse sources. Whilst conventional monitoring practice provides end-users limited access to original data, emerging technologies grant more end-users the means of gathering data to fit their own objectives. As for novice users, which involve a majority of the general public, through receiving easily understandable and proximate information generated by new air quality monitors, they can make informed decisions and potentially increasingly get involved in air quality issues. These data provide an alternative to information obtained from stationary monitoring and official information platforms. The additional measurements may also encourage public engagement to generate local knowledge and supplement local air quality modelling work to support government actions (Yearley et al., 2003; Cinderby and Forrester, 2005; Yearley, 2006). Thus, the use of information from mobile device can potentially nudge behaviour changes and increase social awareness of air quality.

7.3 Explaining end-user stakeholders in the three cities

7.3.1 Grounded theory themes in the three cities

The grounded theory themes emerged from thematic analysis of the qualitative data collected in three distinct cities in Europe and Asia. The five themes were first generated as an outcome of the York analysis, and were then used as orienting concepts for Berlin and Seoul. As the process unfolded, the theme categories became more inclusive, to incorporate a variety of issues concerning local air quality monitoring practice in cities that vary in multiple aspects such as size, culture and environmental institutions. The research did not seek to compare air quality monitoring practices in York, Berlin and Seoul. Yet, the variation in the theme meanings of each case study reveal differences and similarities in air quality management and the application of monitoring practice using low-cost sensors between the cities, as well as between the different end-user stakeholders, i) governmental and ii) social.

One of the main differences between the cities within the central theme of awareness and willingness was the relationship between public attitudes and behavioural change. The results from the two European cities suggested that there is a lack of public awareness of local air pollution. This suggestion tallies with wider public opinion surveys, which typically find that the environmental issue that most concerns EU citizens is climate change. For example, a public opinion survey of Europe found that climate change was the environmental issue of most concern among four topics in 11 Member States, including Germany (63%) and the UK (58%) (European Commission, 2017b). In the UK, a recent national survey also found that climate change was the most important environmental issue, which was mentioned by 26% of respondents (Defra, 2018). Air pollution ranked the fourth chosen by just over 10%, and the majority of respondents (56%) knew “a little” about the adverse impacts of poor air on human health (ibid). This finding fits with the perception of York participants (for instance, interviewee_Y1, Y2, Y5, Y7, Y8), as air pollution was perceived as being invisible in York. When focused on the quality of air locally, around half of the respondents in Yorkshire and the Humber believed the local air quality was good (48%) (ibid). In Germany, 23% of people felt air quality has improved over the last 10 years, that was 10% higher than the average percentage of the 28 Member States (European Commission, 2017b). In the capital, over 70% of Berliners were satisfied with local air quality (Eurostat, 2016). The result also fits the research finding in Berlin. Interviewee_B7, B8 indicated that air pollution is background issue and not a concern on a daily basis. Hence, despite the fact that the annual average air quality objectives for York and Berlin are still being breached (City of York Council, 2015a, Senate Department for Urban Development and the Environment, 2014, see also Chapter Four and Chapter Five), public opinion surveys suggest that the wider public remain largely unaware of this and of the consequences for their health and well-being.

Nonetheless, the findings of Seoul indicated that there seems to be a gap between awareness and willingness. While air pollution was selected by 52% of respondents as the primary issue people were concerned about in 2011, 69% in 2006 (climate change ranked in the third place with 9.1% response rate, Woonsoo Kim et al., 2011), the concentrations of atmospheric pollutants are still problematic in the metropolitan area (more details see Figure 6-9, Chapter Six) and the interviewees suggested that the general public remain unwilling to change their behaviour. One possible explanation is that emission reductions need to compete with other daily interests (for instance, Interviewees_S3). Previous studies show even protective measures by Koreans are affected by multiple factors, not only the knowledge of air pollution but also the satisfaction level with both Korea's and China's efforts on air pollution management (Shapiro and Bolsen, 2018). Surveys also capture that respondents believe the responsibility for change lies elsewhere: respondents surveyed in Germany and the UK considered the most effective way to tackle air-related problems is to apply "stricter pollution controls on industrial and energy-production activities". The response rates were 41% and 35% in Germany and the UK, respectively (European Commission, 2017b). Overall it seems that the public often have limited motivation to change individual behaviour and when changes do happen they are not primarily driven by concerns on air pollution (Defra, 2018).

In general, the research results indicate that public awareness is a critical factor in air quality management, yet a good level of public awareness does not necessarily lead to behavioural change for the reason of air quality improvement. Among the case studies, air pollution is either not a priority issue (in all the three cities) or falls below other topics such as climate change (in the two European cities) in terms of level of environmental concern.

The themes together underline the complexity of urban air quality. As the urban setting and related governance structures widened and diversified in the three case studies, the theme contents were extended. On State and Progress, whilst the findings of York suggest that NO_2 was the key substance of concern for legal air quality objectives, in Berlin and Seoul PM reductions were the key challenge, particularly the levels of PM10 for Berlin and PM2.5 for Seoul. This difference reflects in part the varied environmental institutions and established air quality objectives in Europe and in South Korea (Power and Influence).

As member states of the EU, Germany and the UK are required to comply with EU regulations, although there is scope for diversity in national strategies for reducing ambient air quality (see Chapters Four and Five). EU decision making depoliticises the issue at local level as decisions are taken elsewhere which can act to disempower local policy makers. According to the EU Air Quality Directive, PM2.5 objectives are set for national governments but not local authorities to meet. Hence, the management of PM2.5 is not an administrative duty of the two European local authorities (Responsibility). As a result, there is less political willingness to address the issue (Willingness). As for PM10, along with the improvement of vehicle technologies (Euro standards) and the implementation of local transport policies (such as low emission zone), the PM10 levels are relatively well managed. York has met the national air quality objectives for PM10 and Berlin has achieved a significant reduction. Yet, exceedances occur, and further reduction remains a challenge, largely due to the properties of PM. Unlike NO_2 which is mainly attributed to road transport emissions in urban areas, PM consists of a complex mixture of particles and droplets in the air emitted from a range of sources, and the behaviour of PM varies according to meteorological conditions. Local environmental authorities are limited in the tools they have at their disposal to control complex emission sources especially those transported from the other regions and countries. This question of transboundary pollutants was a key challenge for the Seoul metropolitan government. While PM2.5 has been made as a policy priority, the megacity government is also concerned about both NO_2 and PM levels, including PM10 and PM2.5. To achieve the target, a wider scope of collaboration is necessary for the metropolitan government of Seoul. As such, the findings in York suggested that intra-governmental cooperation is required for effective air quality management at both local and national levels, especially with respect to the transport management. The case studies of Berlin and Seoul revealed the importance of international cooperation and collaboration vis-à-vis trans-boundary pollutants (Power and Influence).

Furthermore, the findings indicated that austerity (Power) emerges as a key variable affecting air-quality monitoring practice in the two European cities, particularly in York. According to the participants, limited financial resources not only affected the number of diffusion tubes employed in York for NOx monitoring (State), but also demotivated local officers in their daily work (Willingness). As for Berlin, although financial capability is one of the main considerations when evaluating additional efforts in monitoring practice or traffic control measures, austerity did not affect the operation of existing monitoring practice (Power and Influence). As such, even when common EU rules are applied in York and Berlin, differences emerge. One of the explanations is related to the impact of the global financial and economic crisis in the late 2000s upon the EU. Burgeoning literature suggests that the crisis has some but limited impacts on EU's environmental policy ambition but calls for sub-national studies (Burns et al., 2019). The findings of this research provided details of how austerity is playing out at the local level in member states where the effects of financial crisis are different.

Despite the differences between the three cities, the results illustrate that ambient air quality monitoring is an imperative part of air quality management. It is essential to collect measurements of concerned pollutants in order to evaluate the status of air quality and to support informed policymaking for addressing local and trans-boundary air pollution problems. The results confirmed that the primary function of monitoring practice is to support regulatory compliance-checking. For such official routine monitoring, the analytical capability, long-term reliability, and accuracy of monitoring equipment are all strictly regulated. The locations and number of monitoring stations are also prescribed. Nonetheless, the findings highlighted the socio-cultural aspect of monitoring practice by outlining the uses of new monitoring technologies to fit various non-regulatory purposes from end-user stakeholder perspectives.

The end-user stakeholders can be classified into governmental or social groups in accordance with compliance and non-compliance monitoring purposes. To better understand the needs of different end users and the role of monitoring, this study tentatively proposed another way of grouping, based on the data uses, end-user stakeholders can be divided into: i) direct end-users of technology and ii) end-users of air quality knowledge. Under current routine monitoring practices, the first group mainly refers to civil servants who carry out measurements and maintenance of the existing network. The second group of users may have limited knowledge of atmospheric chemistry or the advanced sensing technology deployed, and they are more interested in deploying processed air quality information. This group may include policymakers, environmental NGOs, other interest groups as well as the general public. Yet, it should be noted that the classification only focuses on the likely function of air quality data, there is no clear boundary of the two groups and certain overlaps exist (see also table 7-2).

The attitudes of different end-user stakeholders towards new monitoring practice may differ and are affected by the perceptions of end users as well as the local politics of air quality issues. In general, end users interested in non-regulatory purposes are more positive about the deployment of new monitoring practices, particularly environmental NGOs. For instance, environmental activists in York and Berlin implied that the portable devices could substantially support public engagement practices as a communication tool. The availability of additional information could be used to change the opinion of those opposed to “unpopular” policy initiatives to address road traffic emissions. In York, the participants suggested that the failure of Lendal Bridge traffic ban has led local politicians to be cautious about restrictive traffic control measures. The findings also revealed that the public could not easily access and understand air quality measurements under the current information infrastructure, which affected the recognition of local air pollution problem. The lack of awareness may lead to a low level of acceptance of control measures. The interviewees suggested that better information provision could increase public awareness of the impacts of exhaust emission on human health and could build up political will to implement control measures again. In Berlin, the scandal of real driving emission tests for diesel cars has raised worries about transport emission reduction at the administrative level, yet, air pollution was not a political concern. The participants suggested that alternative air-quality monitoring practice could empower environmental activists and citizens to be more active in city development and traffic management. In Seoul, which has a well-developed information infrastructure, high levels of public awareness and relatively strong political will, there nevertheless remain limitations in raising public motivation. There is still scope for new forms of monitoring to support NGOs in their watchdog role and in lobbying the government, for instance by promoting international dialogue with China. It could also provide personalised information to advise the public on taking protective measures. Thus, the findings suggest that environmental NGOs who aim to raise public awareness and influence policymaking are central end-user stakeholders for emerging air quality monitoring practices.

As for compliance, one of the main issues that emerged from the interviewees in the three cities was data quality. Across the end-user stakeholder groups of the three cities, there was a consensus that due to the poor technical performance (see, for example, Lewis et al., 2016, Castell et al., 2017), low-cost sensors have limited potential in current *official* air quality monitoring. Hence, the interviewees generally seemed to regard current urban air quality monitoring as fit-for-purpose. When evaluating the potential and function of monitoring practice using non-conventional tools in particular, the purpose and social context of deployment need to be taken into account. Emerging monitoring practice may not fit the requirements of regulatory monitoring, nor contribute to immediate emission reductions. Nevertheless, new monitors can be deployed by social groups and extend the networks of people involved in the politics of urban air quality. Underlying these diverse purposes of air quality monitoring is the complexity of this collective environmental problem, which is inextricably tied up with the politics of air pollution. Following the grounded theory approach, the next section focuses on how the findings fit or challenges assumptions in the literature on the politics of air quality pollution.

7.3.2 Politics of air pollution

While regulatory instruments have a clear role to play in managing emissions, decision-making processes and the enforcement of related policies are more complex. There is a vast literature on the politics of environmental pollution (e.g. Weale, 1992; Young, 1994; Schneider and Volkert, 1999; Elliott, 2004; Carter, 2007; Knill et al., 2010; Carter, 2013; Finger and Princen, 2013). More specifically a large number of studies have focused on atmospheric problems (see inter alia, Jones, 1978; Elliott et al., 1999; Bickerstaff and Walker, 2001; Selin and VanDeveer, 2003; Yearley et al., 2003; Bickerstaff, 2004; Binder and Neumayer, 2005; Cole et al., 2005; Yearley et al., 2006; Lidskog and Sundqvist, 2011; Barnes et al., 2018). A variety of themes emerge on the process of policymaking relevant to this research: 1) The power of industry, 2) The challenge of international cooperation, 3) The changing political context and role of expertise in air pollution management, 4) The influence of environmental groups and the role of individuals.

1) The power of industry

Attention inevitably centres on emitters, such as, power plants, the chemical industry and the metal industry. Being a significant stakeholder regarding air quality management, industrial representatives, such as car manufacturers, are often engaged through an air quality policy cycle (Cole et al., 2005, Lidskog and Sundqvist, 2011). Elected politicians are obliged to represent the public interest in clean air but may also need to consider the impacts of regulating pollution, which may limit production, on economic growth. In this process, polluting industrial interests maybe opposed to those of some citizen groups who advocate more stringent emission control policies. As a primary function of politics, the government needs to reconcile such conflicting interests and deals with the economic trade-offs implicit in air quality governance (Gibbs et al., 2002, Wurzel, 2002, Carter, 2007, Lidskog and Sundqvist, 2011). Yet, industries may exert pressure at the political level and affect the formulation of related emission control regulations. For example, today the automobile emission control regime of the state of California, United States, is well established, yet it has experienced years of trial (Krier and Ursin, 1977, Gonzalez, 2002). At the early stage of the policy cycle, the representatives of automobile-related industries were very influential in the initiation and formulation of vehicle emission standards as they were the majority of the policy community (Gonzalez, 2002). As such, there was a tendency of relying “exclusively on technology” to lower exhaust emissions instead of limiting the number of automobiles on the road to reduce the impact of car producers and by extension economic growth (ibid.). The findings of this PhD thesis revealed similar influence of industries on air quality improvement. Notably the challenge of reducing NOx levels and the unintended consequences of dieselisation for air quality in Europe (Bonilla, 2009; Schmidt, 2016). The participants indicated that the NOx reduction targets were made based on the assumptions that the environmental performance of diesel vehicles would be improved, and the EU vehicle type approval would be effective. While the on-road diesel fleet continues to grow as a result of dieselisation to reduce carbon emissions in Europe, the fall out of dieselgate proved that diesel engines failed to reduce tailpipe emissions. As such, achieving limit values of NO_2 is more difficult in the two European cities.

Road traffic is one of the main source of emissions in urban areas, consequently the transport industry, and car manufacturers in particular, plays an important role in addressing exhaust emissions. According to the interviewees both vehicle manufacturers and the national government bear the responsibility for delivering effective vehicle emission standards. The automotive industry, due to the expertise and resources especially with respect to diesel cars, is an influential group in relation to the formulation of more stringent vehicle emission standards. The local authority, whilst responsible for local air quality and transport management, does not have power to regulate on-road diesel vehicles. This research revealed that the industrial responsibility in reducing road traffic NOx emissions cannot be overlooked which requires a higher level of co-ordination. As such, co-operative efforts at the national level to deliver an effective and inter-sectoral policy for vehicle emission reduction is necessary.

2) The challenge of international cooperation

Tackling emissions from road traffic and other domestic emission sources alone cannot solve the problem. Contaminants can travel from another region, or even another state, which makes international cooperation indispensable for reducing concentrations of harmful substances in the air. This issue was central to the Seoul case study in particular. Internationally, governmental bodies actively monitor air quality and governments that have made regulatory efforts to control air quality still face baseline levels of atmospheric pollutants which have been produced outside of their regulatory reach. To address this issues states have cooperated to develop international agreements, the best-known of which is the Geneva Convention on Long-Range Transboundary Air Pollution (CLRTAP) (UNECE, 1979). The Convention was the first legally binding agreement to address air pollution at the international level and involved a long process of negotiations and science-policy interplay (Tuinstra; et al., 2006, Lidskog and Sundqvist, 2011). Despite the East-West conflict at that time, international consensus was achieved by acknowledging the need for scientific cooperation, as such CLRTAP is often deemed a success story in international environmental policy formulation (Lidskog and Sundqvist, 2011). In order to provide a scientific baseline for implementing policy measures to reduce levels of air pollution, WHO released updated air quality guidelines which set guideline values for air pollutants (WHO, 2000). Specifically, the 2005 air quality guidelines provided thresholds and limits for key atmospheric pollutants that pose harmful effects on human health (WHO, 2006). Nonetheless, the recommended guideline values are based on scientific evidence only, national authorities were directed to set national air quality objectives taking into account of their own capacities involving economic, political and social factors, as well as technological feasibility, and implement plans to achieve the goals in a reasonable time (WHO, 2006). As such, legally binding air quality standards and strategies differ across and within states as demonstrated by the research findings. Within the EU, the air quality directives (e.g. Air Quality Directive 2008/50/EC) allow action to be taken. In areas where no supranational entity or overarching cross-boundary environmental law exists, international cooperation on reducing transboundary pollution can be orchestrated through non-legally binding agreements. For example, South Korea, Japan and China committed to addressing regional air quality issues through an annual meeting, Tripartite Policy Dialogue on Air Pollution (TEMM, 2016). Yet, effective international cooperation on environmental issues is often challenging to achieve. The political understanding of air pollution varies in each nation due to differences in culture, policy regimes, economic conditions and international relationships among countries (Yearley, 2004; Carter, 2007; Lidskog and Sundqvist, 2011).

This research also found that international cooperation is a key component of air pollution abatement. Within the EU, the European supranational authorities are able to co-ordinate international negotiations and establish legally binding objectives for reducing concentrations of atmospheric pollutants in the Member States. Whilst the EU has created system for cooperation it has potentially disempowered York and Berlin in managing local air quality. Both of the cities have limited opportunities to develop home grown strategies and targets as air quality objectives are established at a higher level. For example, PM2.5 is not a responsibility of local authority that is addressed at the national level. Outside the EU, in the absence of a central coordinating body with political authority addressing trans-boundary air pollution is more challenging. For instance, the findings of Seoul case study suggest that the local reduction targets of Seoul are affected by the transported particles from other nations (e.g., China and Mongolia). International relations and public perceptions on domestic and international efforts are all influential for establishing cross-country policy initiatives. The presence of trans-boundary pollution gives citizens of Seoul and municipal government a potential excuse – there is no point in acting as there is an international source. Nevertheless, the existence of TEMM and municipal dialogues, such as the 'Seoul International Forum on Air Quality Improvement', suggests that there is political willingness to overcome the obstacles to reach air quality improvement targets. The means for achieving environmental policy outcomes and how effective the approaches are would largely depend on the domestic political factors as well as public willingness to change behaviours towards cleaner air.

3) The changing political context and role of expertise in air pollution management

Science has played an important role in shaping environmental regimes. In the late 1960s, the transnational effect of sulphur dioxides on Scandinavian freshwater acidification has been found by researchers, and trans-boundary air pollution has been identified as a threat to common European air quality (Lidskog and Sundqvist, 2011). In the early 1970s, scientists have discovered that the anthropogenic chemicals, i.e., chlorofluorocarbons (CFCs), could damage the concentration of ozone (Carter, 2007). In response to these scientific findings, early environmental policies were focused on promoting international cooperation, in the advanced industrialised nations in particular, to address global environmental atmospheric problems such as acid rain attributed to trans-boundary airborne pollutants, ozone depletion and climate change. One of the most important milestones in the process of placing environmental issues on the international policy agenda was the UN Conference on the Human Environment in Stockholm in 1972 (Jasanoff et al., 2004). Since then, several multilateral environmental agreements (MEAs) were developed, such as CLRTAP (Lidskog and Sundqvist, 2011). The MEAs on the global ozone layer protection were developed from the 1980s, such as the 1985 Vienna Convention, the 1987 Montreal Protocol and its amendments. Later in 1992, the Rio de Janeiro Earth Summit further pushed environmental concerns on the policy area by releasing several important documents including the United Nations Framework Convention on Climate Change (UN, 1997).

Yet scientific findings are often provisional and maybe revised. Due to the complexity of these global atmospheric issues, the formation of international regimes is often a long process and the effects on addressing the problems vary (Wurzel, 2002, Jasanoff et al., 2004, Yearley, 2004, Carter, 2007, Lidskog and Sundqvist, 2011; Carter, 2013, Barnes et al., 2014). More recently, an increasing number of epidemiological evidence has linked urban air pollution, particularly PM and NO2, to increased health risks for morbidity and mortality at local level (WHO, 2006, 2014, Royal College of Physicians, 2016). These health impacts in turn incur high economic costs to domestic society. For instance, a recent study found that the total healthcare cost was £41.20 million due to PM2.5 and £1.68 million due to NO_2 in England in 2017 (Public Health England, 2018). The strong evidence correlating air pollution and adverse health impacts highlighted the importance of local air quality management, transport management in particular. As such, there is a shift in the issues of air pollution politics from a concern with achieving international agreements to local policymaking (Jasanoff et al., 2004; Lidskog and Sundqvist, 2011). Overall, the development of these international environmental regimes has mainly involved the interactions between scientists and policymakers at regional and international levels.

Meanwhile, social and political science studies suggest that science and policymaking are often co-dependent (Dimitrov, 2003; Haas, 2004; Jasanoff et al., 2004; Carter, 2007; Lidskog and Sundqvist, 2011) Scientific knowledge needs to be context sensitive and visible to others outside the expert groups, especially the public when addressing collective environmental problems (Lidskog and Sundqvist, 2011). Yet, scientific evidence is often complex, and the public may find them difficult to understand, leading to a low level of interest in air quality issues (Bickerstaff and Walker, 2001; McDonald et al., 2002; Lidskog and Sundqvist, 2011; Kelly and Fussell, 2015). Nonetheless, public legitimacy and support are imperative for the implementation of related policy initiatives towards better air quality at local level in particular. Hence, along the process of establishing such multi-level environmental policy regimes, there is a growing emphasis on the role of greater social engagement and public participation for further actions (Nowotny et al., 2001, Yearley, 2006, Carter, 2007, Lidskog and Sundqvist, 2011). Hence, the innovative low-cost sensors are increasingly taken up by researchers in citizen science studies to make environmental data more socially robust and context relevant (see, for example, Hasenfratz et al., 2012, Bales et al., 2014; Carton and Ache, 2017).

This study confirmed that increased public participation is a key element of the democratic environmental institutions. However, the changing political context makes environmental claims less attractive to the general public as environmental institutions have been well established in most of the advanced countries. For instance, according to the interviewees of Berlin, local politicians seem to be lacking interest in attending public engagement events for environmental protection. Whilst in Seoul, although there is a strong political will to improve local air quality, public support for new control measures remains elusive. Hence, reinforcing the environmental commitments of political parties and allowing greater engagement in local air quality governance are both important.

4) The influence of environmental groups and the role of individuals

Since the environmental movement in the late 1960s, environmental groups have become a significant force in promoting greener policies to protect natural environment (Jasanoff et al., 2004, Carter, 2007, Lidskog and Sundqvist, 2011). By carrying out various activities, such as lobbying policy elites and obtaining access to decision-making, social actors such as environmental non-governmental organisations (ENGOs) and the general public increasingly participate in the politics of environment. Environmental activists can be influential at all levels of policymaking, ranging from international negotiations on climate change, trans-boundary air pollution to local air quality management (Björkbom, 1999; Gulbrandsen and Andresen, 2004; Binder and Neumayer, 2005; Lidskog and Sundqvist, 2011). For example, according to the rulings of the Court of Justice of the EU (CJEU), concerned citizens have the right to go to national court to demand actions provided by the relevant authorities if air quality limit values are breached (European Commission 2014b). As such, ENGOs and activist lawyers across Europe have bought a series of infringement cases in national courts, such as the cases bought by ClientEarth in the UK, so that the governments have to take appropriate measures to meet the air quality objectives “as shortest time possible” (European Commission 2014b, ClientEarth, 2016). By upholding the procedural right to go to court to enforce related environmental laws, environmental groups have strengthened the enforcement of air quality regulations to a certain extent. Such actions have attracted the media attention and subsequently increased public awareness of air pollution related issues (BBC News, 2015a, BBC News, 2015c, The Guardian, 2015).

Although some environmental campaigns have achieved successes (such as the legal challenge of ClientEarth), many environmental groups, small, local grassroots groups in particular, face difficulties in resources and being empowered to pursue their aims (Carter, 2007, Lidskog and Sundqvist, 2011). The involvement of individuals may also pose further challenges to local air pollution abatement. Specifically, road traffic is a key source of NO_2 in urban areas, however, it is difficult to regulate or manage individual vehicle user's behaviour in using private cars (Bickerstaff and Walker, 1999, Schneider and Volkert, 1999, Yearley, 2004, Lidskog and Sundqvist, 2011). Besides, as clean air is public goods, citizens who do not consider tackling air pollution as a priority can free ride on environmentally favourable decisions (Ostrom and Ostrom, 1977; Schneider and Volkert, 1999; Carter, 2007; Lidskog and Sundqvist, 2011). Furthermore, even when the public perceive air pollution as a health risk, most of the public do not understand the science behind the measurements, nor do they relate their daily life to the concentrations of atmospheric pollutants (McDonald et al., 2002; Ngo et al., 2017). One the one hand, the participation of wider society has clearly become a considerable political force in in local air quality governance, one the other, the means in which the local informants could engage in and the credibility of greater participation in urban air quality management remain .

Previous science and technology studies have attempted to explore the role of individuals and the application of various techniques to empower the wider society in local air quality management. For example, Yearley et al. (2003) developed and applied a 'participatory modelling' technique in three cities- Bristol, Sheffield, and York, in the UK in order to investigate the extent to which public knowledge about air pollution could contribute to local air quality management. The community participatory map collected citizen's view on local air quality issues through group discussions which were facilitated with a large map of the city. Results of the case studies indicated that the participatory map representing public insights and understandings of local air quality could provide complementary information to official modelling work which could inform local policymaking (ibid). Local residents had the ability to review the air quality models developed by professionals as the citizens have the insights into various social activities which may not be captured by the official monitoring system. For instance, the exercise of participatory modelling in York played an important role in the process of identifying local air quality management areas (ibid). Ngo et al. (2017) investigated public risk perception on local air pollution and expertise with respect to air quality measurements in Nairobi, Kenya. By organising interviews, focus group discussions and voluntary air quality sampling practices, the study found that public participation and communication between local residents, governmental officials, air quality scientists and health specialists are critical factors in local air quality management. Although the participants commented on the ability of local authority with scepticism, the research revealed that including concerned residents in air quality monitoring practice could help with establishing trust and increasing awareness and advocacy to local actions (ibid).

The findings of this transnational study show that air quality monitoring is a socially constructed and context specific practice. Depending on the social, economic and political context, different cities may face diverse challenges. Nonetheless, the take-up of emerging air-quality monitoring innovation could fit the needs of various end-user stakeholders towards air pollution abatement. Environmental activists, for instance, ENGOs and special interest groups, are arguably the primary end-user stakeholders in terms of using small, portable and low-cost air quality sensors. Such new methods of monitoring could also benefit researchers to communicate with non-academia local informants. For example, the portable sensors can be deployed in the "participatory modelling technique" (see, Yearley et al., 2003) to facilitate the communication between the investigators with local stakeholders and to collect not only qualitative knowledge but also supplementary air quality measurements. The instant and indicative measurements could supplement current monitoring and may positively increase public and political awareness and willingness towards local air quality improvement, contributing to air quality governance at all levels.

Overall, the themes of the research largely overlap and reflect the main topics identified in the literature on air pollution politics. The wider literature underpinned the thematic framework and supported the findings. The shift in air pollution policymaking from an international focus to local management indicated greater participation in air quality governance is increasingly important. The transition is accompanied with the availability of accumulated scientific evidence on the adverse effects of air pollution on human health and political challenges in reducing road traffic emissions. Such context and challenges of urban air quality management shed light on the take-up of emerging monitoring technologies and the involvement of more citizens. The research found that air quality monitoring is a multi-purpose societal activity which can be more inclusive in terms of who can use monitors and the reasons for doing so. Non-regulatory monitoring practice can be a platform for bridging political and social forces to change attitudes and behaviours towards cleaner air. As such, the end-user stakeholder framework supplements the existing literature on the politics of air quality by providing a social-technological perspective and conceptualises the role of various users. The framework also recognises the ethical position of monitoring practices for addressing the collective environmental problem.

7.4 Chapter conclusion

This chapter discussed the findings presented in the analytical chapters (Chapter Four, Chapter Five and Chapter Six). The discussion was grounded in the original empirical data collected via fieldwork, literature reviews, the context of each case study and from documents reviewed during data collection. This chapter focused on both the narrative of the research findings and the theoretical development of end-user stakeholder framework.

The first part presented and discussed five themes attained from qualitative data collected in the three case studies. Through analysing the rich data, these concepts, or themes in grounded theory, include heterogeneous dimensions of the research topic. The findings of each theme were contrasted with applicable literature from different fields with more up-to-date empirical evidence, that, in many ways, are consistent with previous studies.

This cross-country research found that despite the diversity of city characteristics, there are commonalities underpinned by the contextual themes. First, a low level of awareness and willingness was revealed as a common threat to air quality improvements from both a governmental and societal perspective. For the public, being unaware of air pollution and its adverse health impacts seems to reduce the support for governmental environmental-friendly initiatives or taking necessary actions to reduce air pollution related health risks. For the governments, limited political awareness and willingness may compromise administrative efforts that are not required by law, such as extra monitoring. Furthermore, limited public concern may discourage the enforcement of governmental actions, restrictive transport policies in particular. These findings are consistent with wider literature on environmental risk perception and environmental psychology. Second, the findings signified that the financial capability of local governments is critical and may constrain the operation of official monitoring networks and implementation of policy interventions. Third, this study indicated that for the adoption of new pollution monitoring technologies, the technical performance of these comparatively primitive air quality monitors is a common concern among interviewees. The data quality limits its utilisation for compliance monitoring.

The findings also identified certain gaps and deficiencies in political and social understanding about air pollution. There was a prevalent assumption among respondents in York and Berlin that a higher level of public awareness would lead to environmentally-responsible behaviour change. Yet, the evidence in Seoul illustrated that air pollution concerns may not translate to behavioural responses. This gap between awareness and behaviour about air pollution mirrors the findings of literature on air quality valuation and public willingness to pay in environmental economic studies. The discussion also reflected that how local air quality issues are dealt with is affected by cultural, political and social institutions. In different countries, political and social understanding of air pollution may vary. For example, air quality management as an issue in international affairs in Seoul is more complex than that is in the European context due to the different governance systems in Europe and in Asia. The discussion highlighted the significance of promoting societal and governmental awareness and willingness in relation to poor air quality, but also illustrated that knowledge alone is an insufficient driver of behaviour change. The research suggests that new air-quality monitoring devices may be particularly useful when deployed for non-regulatory purposes.

The second part of the discussion linked the five themes with stakeholder theory and modified the definition of end-user stakeholders that had been developed at the outset of the research (Chapter Two). This change was made as a response to the thematic findings drawn from the empirical evidence, which simultaneously highlighted the limits to the uptake of new pollution monitoring technologies for official monitoring and potential of utilisation as a wider social activity. The application of stakeholder thinking, and the end-user stakeholder concept emphasised the central role of end-user groups of air quality knowledge, i.e., end-users of data and ultimate recipients of indicative air quality information. This is the primary end-user group of new sensors. The end-users' requirements on technology specification are flexible and purpose dependent. As a result of the discussion, this study not only revised the term of end-user stakeholder, but also developed the concept as a framework that can be used to explore and understand the objectives, needs, and relationships of air-quality data end-users.

Chapter Eight Conclusion

8.0 Introduction

The aim of this research was to establish the needs of end users of air quality data in order to determine the scope for the adoption of emerging air-quality monitoring technologies for cities. To achieve this aim, I developed an end-user stakeholder framework, which was revised in the light of empirical evidence collected from three different municipalities in Europe and Asia: York, Berlin, and Seoul. The process of conceptualising who end-user stakeholders are, involved extending stakeholder theory and was grounded by qualitative data provided through semi-structured interviews. The investigation also involved a review of air quality legislation and environmental governance regimes in the three countries. This chapter draws conclusions in the light of these aims and research questions.

Section 8.1 presents a summary of the theoretical background, research process and findings of the discussion. Section 8.2 lists the main results in relation to the overarching aim and research questions of the study. Section 8.3 argues that the contextual features play a significant role in determining the usability of new air-quality monitoring technologies. Section 8.4 and 8.5 review the research contributions in terms of theoretical and practical aspects. This section presents the ways in which the concept of end-user stakeholder contributes to stakeholder theory and what the social-political implications are for urban air quality improvements. Section 8.6 evaluates the research process, methodological approach and identifies limitations of the study. Recommendations for future research and practical actions for air pollution abatement are highlighted in section 8.7. Section 8.8 provides reflections on the researcher's personal experience of the research process. Finally, section 8.9 presents the overall conclusions of this research.

8.1 Summary of research findings

This research investigated the social and political factors that influence the application of emerging portable air pollution monitoring technologies in cities. The study examined air-quality monitoring and management issues in a global setting by conducting semi-structured interviews in three cities: York, Berlin and Seoul. Guided by grounded theory, the study identified five major aspects (themes) from the rich empirical data, which affect end-user perceptions of new air-quality monitoring practice. The research established a variety of end-users' needs. The contextual factors and purpose-dependent end-user needs together informed an end-user stakeholder framework for understanding and analysing the utilisation of new air pollution monitoring technologies in cities. A key theoretical finding from the research is that extending and leveraging stakeholder theory can help us to understand the complexities that attend the management and abatement of urban air pollution.

The end-user stakeholder framework extends stakeholder thinking by deploying a user-centric perspective in order to provide a new understanding of emerging low-cost air quality monitors for cities. The findings of the study suggested that the utilisation of new sensing technologies and information provision platforms in air quality management is a highly complex and even contentious topic. Despite the involvement of various stakeholders who have competing stances on air quality issues, there was a general consensus from the interviewees about the scope of deploying new devices and data. The analysis shows that emerging air quality monitoring practices fit non-legislative needs. Five themes emerged from the data that were used to underpin the refinement of end-user stakeholder: 1) awareness and willingness, 2) state and progress, 3) power and influence, 4) responsibility, and 5) technological innovation. Of these five, awareness and willingness emerged as a core theme which interacts with and justifies the other four concepts.

The position of different end-user groups, the availability of monitoring tools on the market, and consideration of a city's status within a specific environmental institution also emerged as significant. The proposed end-user stakeholder framework and the findings in this research are not a roadmap towards a comprehensive vision of better air-quality monitoring. Instead, the research provides a snapshot of the progress in the case study cities. However, the findings can inform analyses of the utilisation of low-cost sensors in other cities.

It was revealed in the core theme that a good level of public knowledge of air pollution and participation in policy-making may positively affect the prioritisation and implementation of policy measures towards cleaner air. While considered as an administrative duty, any introduction of new monitoring practice beyond compliance requirements is an additional effort, which is influenced by the political priorities and capacity of governments. Hence, although air quality officials are well aware of the issue, political willingness among politicians to make further attempts to address problems can be limited. Whilst interviewees from York and Berlin suggested that a good level of public awareness of air quality could potentially encourage social acceptance of control policies and increase political will accordingly, so that restrictive measures, such as reduction on car use, could be implemented and accepted supportively, the findings from Seoul suggested that the relationship between knowledge and action is less clear cut. This gap between public awareness and willingness, is also evident in environmental valuation studies using methods of economic studies (Carlsson and Johansson-Stenman, 2000; Royne et al., 2011). Air pollution concern is in competition with other factors such as the desire to use a private vehicle. Meanwhile, it is not a daily interest, as for example pollution may be more visible in winter. As such, a high level of concern about poor air quality and its impacts on human health does not necessarily lead to behaviour change.

In all three cities, information provision and dissemination channels are established. Yet, they are presented in different layouts and formats. In York and Berlin, the contents of the websites are limited and less understandable to the general public. In Seoul, air quality information is disseminated on various platforms including mobile text messaging. The unsatisfactory information provision was perceived by participants as a barrier limiting public knowledge and interest in local air quality issues. Additionally, the study found that a discrepancy exists between national air quality standards and WHO guideline values especially for PM. Achieving 'compliance' in Europe and South Korea, in fact, represents different levels of pollution.

The study further found that although the air quality divisions of governments possess legal power and can in principle provide the necessary material resources and expertise for compliance monitoring and management, their influence on pollution reduction can be compromised due to the complexity of air quality management. Additional efforts, for example, to increase the density of monitoring network or improve existing information infrastructure, are difficult to make when budgets are limited. More importantly, due to administrative boundaries, environmental units can not directly influence other departments to prioritise air quality policies, such as transport departments. Thus, national coordination is required to establish and improve inter-governmental cooperation for the implementation of air quality policies. Meanwhile, as atmospheric pollutants, PM in particular, can travel from distant sources of emission, there is a requirement for greater institutional arrangements not only domestically but also internationally. This is particularly important for Seoul, as local reduction targets are affected by the transported particles from China and Mongolia.

Moreover, it was noted that as the ultimate user of air quality information and the beneficiaries of improved urban environment, members of the public often overlook their individual responsibility while acknowledging the duty of the government and blaming others. As air quality is a public good, one can benefit from improvements without making any effort to contribute to them. For example, when voters participate in local decision making, they may free ride on environmentally favourable proposals of others and vote for self-interest policies (Schneider and Volkert, 1999). Therefore, new methods for high-publicity activities to better inform the citizens about air pollution are of great interest to environmental advocates. New air quality monitors can be used in this way. They are able to demonstrate pollution levels instantly and often provide complementary communication channels via mobile applications. Hence, commercial air quality monitors can be useful for increasing awareness of the moral responsibility of individuals and encouraging environmentally responsible behaviour within wider society.

With respect to measurement instruments, it was realised that the methods used for compliance air-quality monitoring are strictly structured and controlled by official procedures, from positioning of monitoring stations to data management. The technical performance of current lower cost smaller sensors is relatively poor thus the questions of data accuracy remain open (Lewis et al., 2016; Castell et al., 2017), and hence applications using new sensing instruments do not meet the requirements of compliance monitoring. Nonetheless, the findings suggest that other uses of such monitoring practices are of great interest to various end-user groups, environmental NGOs in particular. Such applications do not require accurate and robust air quality data as used in regulatory analysis, instead, the non-routine monitoring practices accept real-time and indicative information. The take-ups show great promise for advancing efforts to widen citizens' involvement in air quality discussions, increasing the level of acceptance regarding restrictive policies, and increasing personal interest towards behaviour change. Further, it is expected that in citizen science research the cost-effectiveness of crowdsensing data could outweigh data quality issues (Gardiner et al., 2012).

Overall, the findings show that air quality improvement is a common challenge in all three cities. Alleviation of air pollution is either not a priority for the public (in all three cities) or not the primary environmental concern compared with other environmental topics such as climate change (in the two European cities). The results show that greater participation and better communication could potentially benefit local air quality management. In an emerging monitoring paradigm, new technologies can diversify end-users' involvement in air-quality monitoring, diverting from legislative-focused compliance monitoring to a multi-functional societal practice beyond legislation. Such practices accompanied by the pace of technology development may positively contribute to air pollution abatement at local, national, and global levels.

8.2 Conclusions to research questions

The research addressed in this thesis has investigated end-user needs and the social-political context of urban air-quality monitoring, in relation to the use of new monitoring technologies in particular. The following section provides findings in relation to the research questions raised in Chapter One.

8.2.1 Research question one: What is the meaning of end-user in the context of urban air-quality monitoring?

In this research, end-users of new air-quality monitoring technologies in cities are individuals and/or organisations who are able to receive and utilise additional air quality knowledge, which is currently not available or not easily accessible through official monitoring practice.

The development of this definition was based on literature on end-users and stakeholders. As such, end-user stakeholders bridge the monitoring technology with its social context. While the debates about end-users focused on distinguishing users and the developers, the term stakeholder captures the relations between a range of actors involved in a specific issue. This research aimed to understand end-users' needs and the contextual factors that shape their perceptions in relation to emerging air-quality monitoring. Thus, the concept of the end-user stakeholder was developed by extending stakeholder theory to the utilisation of new air quality monitors in cities. Therefore, when end-users of urban air-quality monitoring are discussed in this research the term refers to end-user stakeholders.

Depending upon end-users' position in the generation of air quality information, the end-users of air-quality monitoring can be classified into two general groups, namely end-users of monitoring tools and end-users of air quality knowledge generated by such monitoring practices. The first end-user group interacts with sensing tools directly while not necessarily needing to be involved in data management and dissemination. The second group consists of end-users of data who receive raw measurements, take care of data processing and interpretation, and end-users of information who receive the processed and interpreted records of air quality. For the use of new monitoring technologies, there may be overlaps between the groups of technology end-users and knowledge end-users as new sensing tools often generate air quality information in an immediate manner. As such, technology users are information receivers at the same time. Nonetheless, different end-user groups could have distinctive reasons for using such new tools. For example, end-users of monitoring technologies may need the devices to demonstrate the changes of pollution levels, while end-users of information may use the emerging devices for making personal travel decisions.

8.2.2 Research question two: What data do end-users need and why?

End-user needs are defined by their respective reasoning of measuring urban air quality. This research revealed that the perceptions of end-user stakeholders concentrate on two types of objectives, i.e., compliance and non-compliance monitoring. With the purpose of checking compliance with air quality standards and evaluating the effectiveness of management policies, end-users need to have reliable and robust measurements of atmospheric pollutants that meet the requirements of legislation. In such cases, the location of sampling sites, devices used, and data management procedures are all regulated by official documents. With respect to non-compliance purposes, end-users' data needs are less restrictive. Therefore, end-users that are not bound by legal monitoring requirements are more likely to be able to accommodate different types of air-quality monitoring instruments. Depending on the objective of monitoring, the instruments employed may be complex analysers as used in regulatory monitoring but could also be new low-cost air-quality sensors that provide indicative air quality data. Details of a variety of monitoring objectives and corresponding data needs of end-users can be found in Chapter Seven, Section 7.2 and Table 7- 2.

8.2.3 Research question three: What is the role of emerging monitoring practice in urban air quality management?

This research found that given the current state of technology, emerging monitoring practice primarily serves non-compliance objectives and contributes to policy-making on air pollution abatement indirectly. Although new monitoring tools fail to generate air quality measurements as high as reference methods, these applications could be used by individuals and organisations who accept indicative measurements. Emerging monitoring technologies could benefit individuals and organisations who are unable to access original data or easily obtain understandable information in regulatory monitoring practice.

Such non-compliance monitoring could cover a broad spectrum of activities. For instance, by providing extra inputs, the portable devices can be used by the air quality researcher in improving atmospheric modelling. By generating localised near real-time measurements, human health experts could employ portable monitors in personal exposure studies. With technical features that can demonstrate changes in air pollution levels instantly, new air-quality sensors could empower environmental NGOs by increasing opportunities for public engagement and informing the general public with more personally-tailored information. These activities may positively increase the levels of public and political awareness and willingness when dealing with urban air pollution, leading to a higher chance of behaviour and policy changes. Therefore, the findings suggested that emerging monitoring practice could contribute to urban air quality management by supplementing current monitoring practice and widening the scope of societal participation in air quality issues.

8.2.4 Research question four: What are the factors shaping the deployment of new air pollution monitoring technologies in the three cities?

Grounded by empirical evidence from three distinct cities, the study developed an end-user stakeholder framework which revealed five contextual factors (grounded theory themes) that could affect the application of emerging air-quality monitoring practice in cities. They are 1) awareness and willingness, 2) state and progress, 3) power and influence, 4) responsibility and 5) technological innovation.

Among the themes, this research considered awareness and willingness as the core factor. The analysis of the data suggests that public awareness of air pollution may not lead to behaviour change due to the other competitive daily interests and vehicle dependency. Yet, bringing awareness of air pollution to the public is a critical step for addressing social inertia to change and increasing social acceptance of restrictive transport policies. As such, it also motivates and injects political will earlier in the policy-making process, especially in representative democracies. This core factor interacts with other themes in various ways. For instance, the findings implied that awareness and willingness could affect the status quo of urban air quality by influencing local policy prioritisation and implementation of political initiatives. Meanwhile, the state of the issue, for example, visibility of air pollution, could affect the individual perception of local air. Likewise, the rest of the factors are interlinked. Together, they shape the social and political scope for the deployment of emerging air-quality monitoring tools. Explanation of the themes and their relations are detailed in Chapter Seven Section 7.1.

8.2.5 Research question five: How can we best ensure that established practices are updated to allow for the adoption of emerging technologies?

The study found that established urban air-quality monitoring practice in cities is primarily driven by legal requirements and legislative pressure on relevant government bodies to comply with national and international air quality laws. Thus, the operator, devices used, and management of generated data should all be legitimate if new air-quality monitoring practices are to be used for a regulatory purpose. Due to the current state of monitoring technology, replacing or incorporating official networks with emerging methods of measurement seems to be impractical. Nonetheless, the findings suggested that new air-quality monitoring practice could supplement existing routine monitoring networks and could be taken up by a wider society if the data fit a specific purpose and the data quality are acceptable to particular end-users, see also Chapter Seven Section 7.2 and research question two.

8.3 Research argument

This study argues that air-quality monitoring as a tool serving urban air quality management does not stand alone. Views of experts on air-quality monitoring mirror how people perceive air quality policies that have been influenced to a great extent by political, social, economic, cultural and technological factors. Thus, the adoption of new monitoring practices is shaped by the context of application. This research makes it clear that new monitoring practice can be a useful tool for promoting a collaboration between social and political forces to tackle urban air pollution.

Given current levels of air pollution and the growing epidemiological evidence of its adverse impacts on human health, there is a need to encourage commitment to address air quality both from the government and society. This research, through its examination of the progress of air quality policies in three distinct cities found that air quality improvements will not be successful if there is no effective involvement of the general public. Effective management of urban air pollution also requires long-term coordination and collaboration between government branches horizontally and vertically. In addition, material resources, expertise and technical solutions are all critical to reducing emissions. As a result of the complexity of air quality issues, despite the exercise of diverse legal instruments and policy objectives, air pollution is still a challenge to address especially in highly urbanised areas. Therefore, the potential benefits of using new air-quality monitoring methods in non-compliance uses should be recognised.

8.4 Research contributions and implications

8.4.1 Contribution to knowledge

The primary contribution of this project is the development of an end-user stakeholder framework and its application in urban air quality issues from both theoretical and practical perspectives. The concept of the end-user stakeholder connects two sets of literature. The first, end-user studies, comes mainly from the field of computer science, which discusses the role of user in the introduction of programmed product. The second set of literature, stakeholder theory, has been extensively debated and applied in various disciplines. By extending the theory in the context of urban air-quality monitoring, the research identified the intricate network of stakeholders and the involvement of end-user as salient stakeholder in the system. Thus, the conceptualisation of end-user stakeholder on one hand adds to literature about end-user classification in the context of applying new air quality sensing tools in cities. On the other hand, by developing the concept, this research broadens the application of stakeholder thinking in urban air-quality monitoring issues.

Furthermore, by applying a grounded theory methodology in a transnational analysis, the end-user stakeholder concept has been developed as an investigative framework and gained instrumental value. The themes were first identified based on qualitative data collected in York, and further refined by the results of subsequent data analyses of Belin and Seoul. As such, the framework can be used to interpret the deployment of emerging monitoring tools in diverse urban settings. It provides a helpful tool for researchers interested in the use of new air quality monitors and end-user participation in different urban settings.

Secondly, the study adds empirical evidence to the debate about the relatively poor performance of emerging low-cost air-quality sensors and the effects of data quality on the take-up of new technologies in real-world conditions from diverse end-user perspectives. While a number of studies focus on technical specifications and performance of available products (for example, Lewis et al., 2016; Castell et al., 2017; Kelly et al., 2017; Rai et al., 2017), or aim to develop new sensor networks (see Mead et al. ,2013; Hasenfratz et al., 2012; Snyder et al., 2013; Bales et al., 2014; Schneider et al., 2017), this research investigated the multi-dimensional context of utilisation and explored the implications of different monitoring practices for air quality management in practice. The outputs reflect the values of research participants, which are affected by their social and political positions. Despite the diversity of contexts, the findings suggested that there was a consensus that new air-quality monitoring technologies have great potential for non-compliance purposes, such as for practitioner activities and citizen science research.

8.4.2 Implications for policy and social practice

In addition to the main intention of contributing to academic discussion about the use of emerging air-quality monitoring technologies in cities, this research provides a new evidence base for policy makers and environmental advocates to enact actions towards air quality improvements.

This study was not primarily about air quality management. Yet, since the measurement of atmospheric pollutants is one of essential foundations of policy-making, air-quality monitoring provides useful insights into how air quality policies are implemented and what challenges governments face when it comes to enforcement. The findings have highlighted the importance of involving wider society in managing local air quality and the need for considering monitoring practice beyond legislation. As such, local administrations could collaborate with key end-user stakeholders to perform monitoring activities and to improve how air quality information is communicated in order to support policy interventions. Such engagement activities are likely to be overlooked if air-quality monitoring is considered as a tool solely for compliance purpose.

Additionally, the research has underlined the significance of enhanced coordination and in-depth collaboration between governmental organisations from perspectives of diverse end-users at multiple scales. The empirical data hinted at potential areas to work on for achieving the management goal of air quality administrations and how their respective capacities could be affected by other government departments, such as the transport department.

With respect to environmental advocates, this research has shown that they are one of the primary end-user stakeholders who are likely to take-up and integrate emerging monitoring practice into their practitioner activities, ENGOs in particular. The research findings presented the ways in which end-user stakeholders are related to diverse air-quality monitoring practices and potential contributions of such practices to air pollution abatement. Many of these activities overlap with ENGO objectives, such as, raising public awareness, promoting an environmental-friendly lifestyle, holding government accountable, lobbying and campaigning for pro-environmental decision-making. As such, the end-user stakeholder framework and findings of this study can be used to develop strategies for scaling up the impacts of ENGO operational initiatives on air pollution issues and promoting empowerment of ENGOs as well as the citizens for air quality improvements.

8.4.3 Implications for emerging environmental monitoring

Urban air pollution is an exemplary environmental problem, which is highly complex due to challenges in source apportionment, chemical reactions, as well as the involvement of a wide range of domestic and international stakeholders. Air quality is also central to health and can determine whether protective measures need to be taken on a day-to-day basis, for vulnerable people, such as people those with respiratory conditions. Still, there are similarities between air quality and other urban environmental issues. For instance, like air quality, water and environmental noise levels are also regulated and monitored. In the EU, water quality and noise levels are mainly regulated by the EU Water Framework Directive[55] and the EU Environmental Noise Directive (END)[56], and the issues are primarily dealt with by the Water Quality and Ecosystem Conservation Act[57] and Noise and Vibration Control Act[58] in South Korea. By collecting water samples in different locations, water quality is monitored using chemical, physical, or biological measures (Bartram et al., 1996, Strobl and Robillard, 2008). Noise is not of a chemical nature and could be detected using portable sound level meters (Maisonneuve et al., 2009, Maisonneuve et al., 2010). Yet, for other types of urban pollution or emerging contaminants, such as engineered nanoparticles, scientific knowledge is limited, sensitive and robust detection methods are not yet established (Tiede et al., 2008). Nonetheless, knowledge of environmental pollution is necessary in order to support well-informed policymaking, develop improved and effective strategies to manage urban environment, and proactively prevent potential future problems.

The availability of new monitoring methods may supplement existing urban environmental data. For instance, Carton and Ache (2017) investigated the application of sensor networks in two community

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[55] Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32000L0060
[56] Directive 2002/49/EC of the European Parliament and of the Council of 25 June 2002 relating to the assessment and management of environmental noise - Declaration by the Commission in the Conciliation Committee on the Directive relating to the assessment and management of environmental noise. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32002L0049
[57] Water Quality and Ecosystem Conservation Act. http://www.moleg.go.kr/english/korLawEng?pstSeq=47543
[58] Noise and Vibration Control Act. http://www.moleg.go.kr/english/korLawEng?pstSeq=47533

initiatives in the Netherlands to collect information on noise and gas extraction-induced earthquakes respectively. Supported by the technical experts, the local communities established non-official monitoring networks to collect and share information that they were concerned about. The study found these monitoring practices, which used networked sensors, filled a gap in environmental data. These practices have broken the information monopoly of the government on environmental measurements and empowered citizens to become more active in local environmental governance (ibid.). The findings of this research also indicated that supplementary air quality information may positively attract public interest in air quality issues and empower ENGOs in local air quality management.

Hence, the advantages of non-compliance monitoring using low-cost sensing technologies are not limited to air quality but may be applicable to other urban environmental problems. Although data quality is an issue of concern for emerging low-cost instruments, non-compliance environmental monitoring may advance the "sense-making" of urban environmental data. New monitoring activities enable us to get a better understanding of the source of pollutant, pollution hotspots in cities, support epidemiology studies and inform policymaking. Also, by collecting additional (if monitoring regimes exist) or new (if no official monitoring exists) data, wider society could be empowered, engage in, and potentially become more supportive in local environmental management towards sustainable and liveable environments for all.

8.5 Significance of the research

To the best of the researcher's knowledge, this is the first transnational qualitative research that has investigated the social-political context of using emerging low-cost air-quality sensors and its potential impacts from end-user perspectives in the UK, Germany and South Korea.

While a number of studies have investigated technical issues related to the utilisation of emerging low-cost personal sensors, this research provided a new interpretation and complemented previous studies with recent empirical evidence at different scales. Specifically, there are projects focusing on the evaluation of technical features and performance of new air quality monitors, such as what pollutant the sensor can measure, how the device performs in real-world conditions, and how good the data are compared to reference methods (for example Lewis (2016), Castell (2017), Kelly (2017) and Rai

(2017)). Some others aim to develop monitoring platforms and to engage with the public in monitoring activities (for example Hasenfratz (2012), Bales (2014)). This research has extended the discussion to explore the social and political grounds of applying new air-quality sensors in different cities. Cultural and historical influences of the city regarding of the level of and political attitude towards air pollution were also taken into account. The findings were supported by original in-depth expert interviews at local and national levels.

Additionally, existing studies and international research collaborations regarding new air-quality sensors for cities are heavily concentrated on the Western countries particularly within Europe. Yet, as air pollution is a global environmental health concern, it is necessary to consider the diversity of cultural, policy and social context for air pollution abatement. By bridging three cities in Europe and in Asia, this study was an attempt to broaden the understanding of emerging air-quality monitoring with new empirical evidence at local, national and global scales.

8.6 Limitations

8.6.1 Interviews

This research employed expert interviews only. The interviewees were regarded as experts who are knowledgeable about environmental issues and experienced in their jobs or personal life. Expert interviews allowed the researcher to gain in-depth information about the research topic efficiently. However, the general public, a key end-user groups, were not included in the data collection (this is dealt with by another study of the parent project). The selective interviews may have limited the findings to a certain degree. Nonetheless, this study received contribution from experts who often collaborate with general public and commented upon the views of that wider public.

Furthermore, due to location constrains, Skype and telephone were used for some interviews. Technical disconnection happened unexpectedly and interrupted conversations, and no observation could be made. The technical interruptions may have affected the effectiveness of the communication. In such cases, information obtained from other interviews and secondary data related to the specific case study were used to compensate and justify the findings.

In addition, more than half of the interview participants, and the researcher use English as a second language. Words used by participants may have multiple meanings and can be interpreted in different ways. Thus, the language barrier may have limited the information obtained during the conversations and during the analysis.

8.6.2 Case study cities

This research collected primary data from three different cities which have distinctive characteristics. Nonetheless, all of them are located in developed economies which have a representative democratic political system. As the developed end-user stakeholder concept is context dependent, the findings of this study, i.e., analytical results obtained from perceptions of interviewed participants, may not be applicable to cities with different social and political contexts. Yet, the thematic framework is broad and includes various aspects of urban air-quality monitoring practice. Therefore, it can be an instrument to start exploring the issue in other urban setting, even cities without established air-quality monitoring-networks.

Secondly, the analysis of Seoul may have been compromised by more limited data availability and time constraints. The identification of research participants was supported by research collaborators from Seoul National University. There was also support from the British Embassy. Face-to-face interviews were arranged beforehand due to the available time for conducting fieldwork in Seoul. Grey literature, such as policies, databases, reports produced by relevant institutions, were not easy to obtain or not available in English. Thus, this data for this case in particular may have been biased. The research has employed international reports, for instance, reports of OECD, to verify the findings as much as possible.

8.6.3 The narrative of findings and conclusions

In order to keep within the core ethos of grounded theory, the literature related to the thematic concepts were not engaged until the framework had been refined at end of the third analytical case study. Although various aspects of extant knowledge, such as social, political, economic, psychological, chemical, and technological dimensions, were linked with the developed end-user stakeholder framework, theoretical ideas and empirical findings from these disciplines were not systematically accessed. This may limit the strength of conclusion and argument of this study in a specific discipline. Still, as a piece of interdisciplinary research, this project integrated diverse perspectives together to elaborate the research topic which is of knowledge value for outlining the challenges related to urban air pollution.

Additionally, air quality and the deployment of sensing technology development are fast-moving fields. The findings of this study were drawn on viewpoints of the participants based on past knowledge and experience. The fluidity of societal values and perceptions of end-user stakeholders, the availability of new specifications of technology or information sharing platforms, new political system and policy prioritisation, can all affect the research outcome. For example, the designated website for disseminating air quality information were all updated in York and Berlin (see Chapter Four and Five) after interviews. While lacking communication infrastructure was regarded as a factor affecting local public awareness and a challenge for local administrations due to financial constraints this perception may now be different. As such, the interpretation of research results is contextual and temporally specific.

8.7 Recommendations

Given the implications of findings and identified limitations of the research, this study recommends that future research could focus on methodological development and application as well as longitudinal comparative studies.

The analysis here was limited to developed economies and representative democracies. To verify and improve the investigative framework, a similar research practice could be conducted in other countries, both those with a similar profile as the studied countries and those which have different economic and political conditions. Further analysis could be done to investigate the effects of the economy and political structure on the adoption of emerging air-quality monitoring practice. Such studies could strengthen the applicability of end-user stakeholder framework in different contexts. For example, air quality data and monitoring devices may be more useful for informing the development of air-quality monitoring infrastructure in states that do not yet have the systems and knowledge to systematically collect such data.

Additionally, this research has highlighted the effect of information infrastructures on local public awareness of air pollution and indicated that change happened after the data collection in York and Berlin. To understand the influence of communication and how the efforts were made, a comparative analysis would be valuable. Such analysis would be able to capture the changes of attitude alongside the improvement of monitoring practice. It could be extended to a longitudinal study over a period of time in order to explore the instrumental value of the framework.

Furthermore, the study recommends broadening the participation of end-user stakeholders so as to include experts from other governmental departments, such as transport administrations, as well as representatives of the public. This would provide more insights and strengthen the findings of the framework.

8.8 Personal Reflection

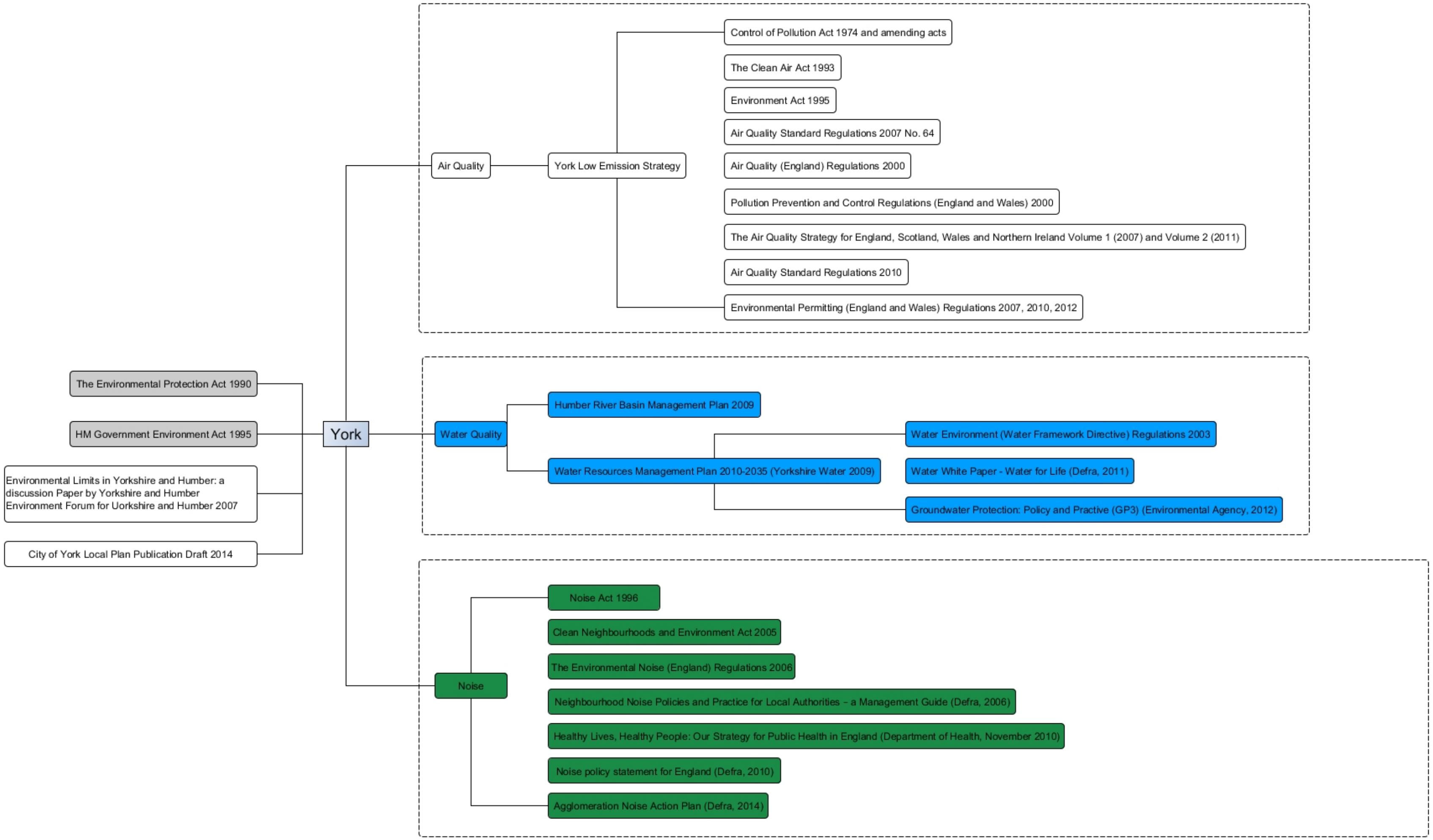
Pursuing this PhD has exposed the researcher to various experiences. First, this project has significantly developed the researcher's knowledge of social science methodologies. By conducting the research, I realised the importance of understanding the social context of and impacts upon an interdisciplinary research. For example, this study was about a fast-moving topic which has received long-term policy attention and growing interest from the society recently. During the course of this study, a number of updates on both policies and social practices have been noticed. The changes were reflected as much as possible in the writing, but the coverage is inevitably limited. Progress has also been affected by external factors. The time of preparing and conducting research interviews in York coincided with the local election and later on the EU referendum. As many experts were engaged in other activities, data collection took a longer time to reach saturation. Such experiences have refined my understanding of research challenges and how scientific projects could be connected with people outside research communities.

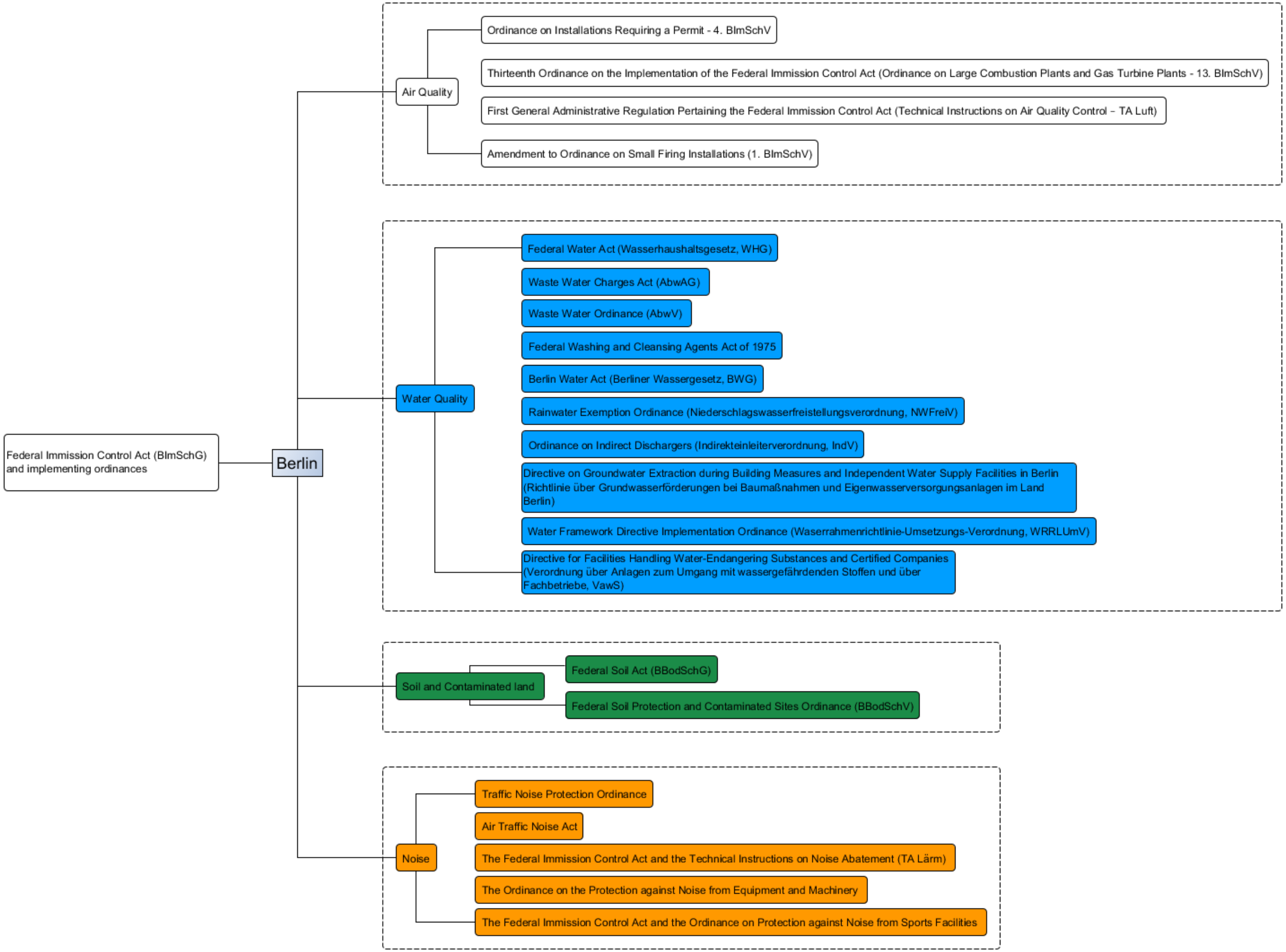
In addition, being part of a bigger research project and research training network, this study has offered the researcher opportunities to work in a multi-disciplinary international team, attend a series of training courses and international conferences. There were also opportunities to participate in outreach activities. Through all the activities, the researcher's transferable skills have been improved.

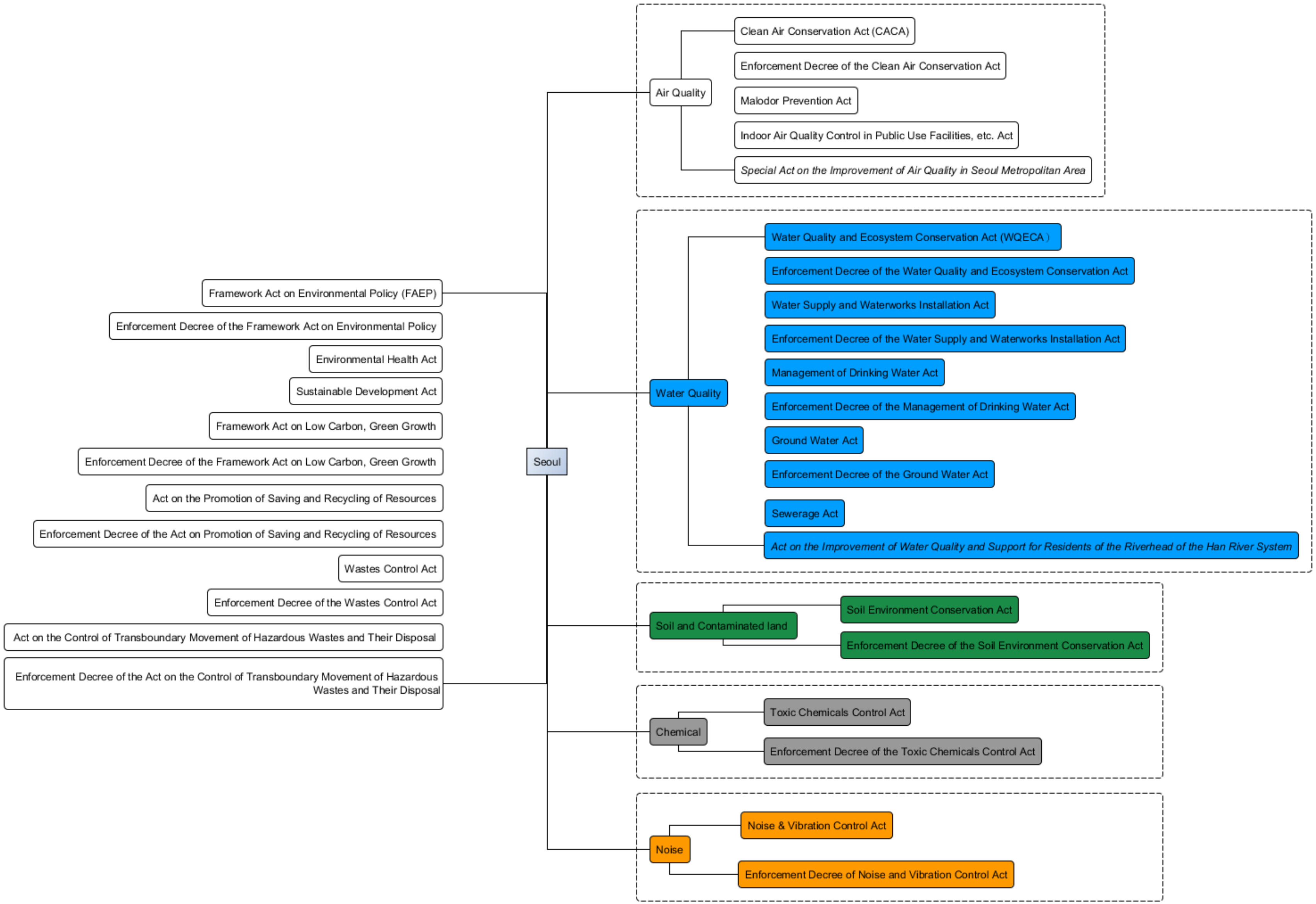
8.9 Overall conclusions

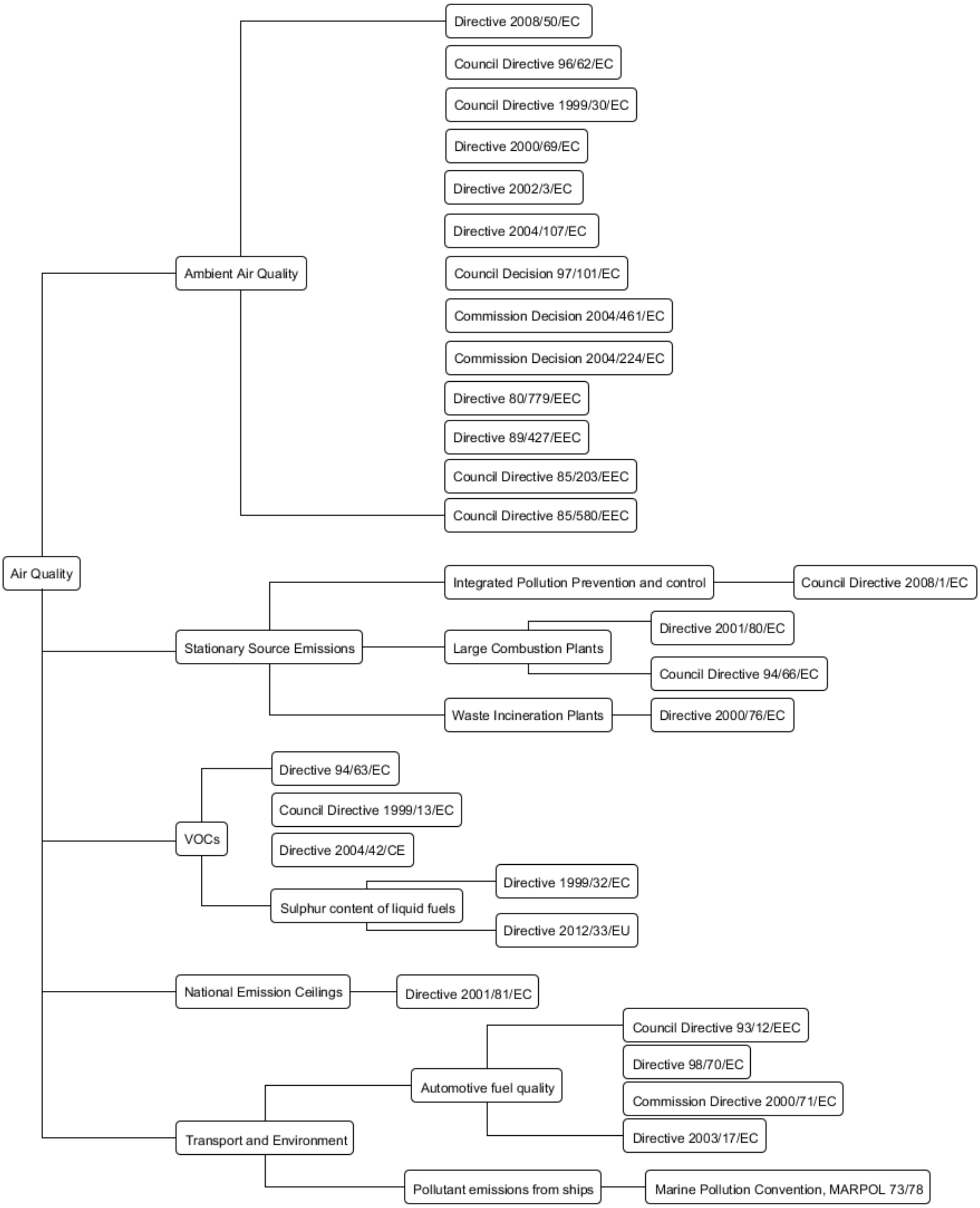
This research aimed to provide a better understanding of the use of new air-quality sensors' in cities by investigating the way in which contextual factors shape urban air-quality monitoring. The principal findings of the study are that emerging air-quality monitoring technologies have potential benefits but are limited by a number of factors. The most important one is the ambiguous technical performance of these new technologies. Currently, the analytical capabilities and data quality of new air-quality monitoring technologies are limited compared to those used in compliance monitoring. Thus, emerging measuring devices cannot be employed for checking compliance with legal requirements. However, these new technologies can be used to meet a range of non-regulatory monitoring objectives. These objectives involve strengthening scientific research, providing additional data for civil society action, enhancing public engagement and maybe prompting behaviour change and increasing political awareness of and willingness to take action to address pollution. As such, these monitoring devices can affect air quality policies indirectly. Only by expanding the discussion of air pollution beyond legislative requirements and employing emerging air quality monitors to expedite data collection and to encourage wider societal participation can we hope to improve urban air quality.

Appendix I Environmental policies mapping exercise for York, Berlin and Seoul




Federal Immission Control Act (BImSchG) and implementing ordinances
Berlin
Air Quality
Ordinance on Installations Requiring a Permit - 4. BImSchV
Thirteenth Ordinance on the Implementation of the Federal Immission Control Act (Ordinance on Large Combustion Plants and Gas Turbine Plants - 13. BImSchV)
First General Administrative Regulation Pertaining the Federal Immission Control Act (Technical Instructions on Air Quality Control – TA Luft)
Amendment to Ordinance on Small Firing Installations (1. BImSchV)
Water Quality
Federal Water Act (Wasserhaushaltsgesetz, WHG)
Waste Water Charges Act (AbwAG)
Waste Water Ordinance (AbwV)
Federal Washing and Cleansing Agents Act of 1975
Berlin Water Act (Berliner Wassergesetz, BWG)
Rainwater Exemption Ordinance (Niederschlagswasserfreistellungsverordnung, NWFreiV)
Ordinance on Indirect Dischargers (Indirekteinleiterverordnung, IndV)
Directive on Groundwater Extraction during Building Measures and Independent Water Supply Facilities in Berlin (Richtlinie über Grundwasserförderungen bei Baumaßnahmen und Eigenwasserversorgungsanlagen im Land Berlin)
Water Framework Directive Implementation Ordinance (Waserrahmenrichtlinie-Umsetzungs-Verordnung, WRRLUmV)
Directive for Facilities Handling Water-Endangering Substances and Certified Companies (Verordnung über Anlagen zum Umgang mit wassergefährdenden Stoffen und über Fachbetriebe, VawS)
Soil and Contaminated land
Federal Soil Act (BBodSchG)
Federal Soil Protection and Contaminated Sites Ordinance (BBodSchV)
Noise
Traffic Noise Protection Ordinance
Air Traffic Noise Act
The Federal Immission Control Act and the Technical Instructions on Noise Abatement (TA Lärm)
The Ordinance on the Protection against Noise from Equipment and Machinery
The Federal Immission Control Act and the Ordinance on Protection against Noise from Sports Facilities


Seoul
Framework Act on Environmental Policy (FAEP)
Enforcement Decree of the Framework Act on Environmental Policy
Environmental Health Act
Sustainable Development Act
Framework Act on Low Carbon, Green Growth
Enforcement Decree of the Framework Act on Low Carbon, Green Growth
Act on the Promotion of Saving and Recycling of Resources
Enforcement Decree of the Act on Promotion of Saving and Recycling of Resources
Wastes Control Act
Enforcement Decree of the Wastes Control Act
Act on the Control of Transboundary Movement of Hazardous Wastes and Their Disposal
Enforcement Decree of the Act on the Control of Transboundary Movement of Hazardous Wastes and Their Disposal
Air Quality
Clean Air Conservation Act (CACA)
Enforcement Decree of the Clean Air Conservation Act
Malodor Prevention Act
Indoor Air Quality Control in Public Use Facilities, etc. Act
Special Act on the Improvement of Air Quality in Seoul Metropolitan Area
Water Quality
Water Quality and Ecosystem Conservation Act (WQECA)
Enforcement Decree of the Water Quality and Ecosystem Conservation Act
Water Supply and Waterworks Installation Act
Enforcement Decree of the Water Supply and Waterworks Installation Act
Management of Drinking Water Act
Enforcement Decree of the Management of Drinking Water Act
Ground Water Act
Enforcement Decree of the Ground Water Act
Sewerage Act
Act on the Improvement of Water Quality and Support for Residents of the Riverhead of the Han River System
Soil and Contaminated land
Soil Environment Conservation Act
Enforcement Decree of the Soil Environment Conservation Act
Chemical
Toxic Chemicals Control Act
Enforcement Decree of the Toxic Chemicals Control Act
Noise
Noise & Vibration Control Act
Enforcement Decree of Noise and Vibration Control Act


Air Quality
Ambient Air Quality
Directive 2008/50/EC
Council Directive 96/62/EC
Council Directive 1999/30/EC
Directive 2000/69/EC
Directive 2002/3/EC
Directive 2004/107/EC
Council Decision 97/101/EC
Commission Decision 2004/461/EC
Commission Decision 2004/224/EC
Directive 80/779/EEC
Directive 89/427/EEC
Council Directive 85/203/EEC
Council Directive 85/580/EEC
Stationary Source Emissions
Integrated Pollution Prevention and control
Council Directive 2008/1/EC
Large Combustion Plants
Directive 2001/80/EC
Council Directive 94/66/EC
Waste Incineration Plants
Directive 2000/76/EC
VOCs
Directive 94/63/EC
Council Directive 1999/13/EC
Directive 2004/42/CE
Sulphur content of liquid fuels
Directive 1999/32/EC
Directive 2012/33/EU
National Emission Ceilings
Directive 2001/81/EC
Transport and Environment
Automotive fuel quality
Council Directive 93/12/EEC
Directive 98/70/EC
Commission Directive 2000/71/EC
Directive 2003/17/EC
Pollutant emissions from ships
Marine Pollution Convention, MARPOL 73/78

Appendix II Review of end-user and stakeholder definitions in literature

Example of end-user definition

Field	Definition	Reference
End User Facility	“a sizeable subset of the users of data processing equipment and its output”	Lefkovits, H. C. (1976). "A progress report on the activities of the CODASYL End User Facility Task Group." ACM SIGMOD Record 8(1): 1-35.
End-user computing (EUC)	"...from the standpoint of the compiler writer, all applications programmers are 'users.' Similarly, to the full time applications developer, all part time programmers (e.g., engineers, analysts) may be 'users.'" "DP professionals (DPP); DP users (DPU). This second category is further divided into DP amateurs (DPA) and non-DP trained users (NTU)"	McLean, E. R. (1979). "End users as application developers." MIS quarterly: 37-46.
	"1. Nonprogramming end-users whose only access to computer-stored data is through software provided by others. 2. Command level users who have a need to access data on their own terms. 3. End-user programmers who utilize both command and procedural languages directly for their own personal information needs. 4. Functiona/support personnel who are sophisticated programmers supporting other end-users within their particular functional areas. 5. End-user computing support personnel who are most often located in a central support organisation such as an "Information Center." 6. DP programmers who are similar to the traditional Cobol shop programmers except that they program in end-user languages"	Rockart, J. F. and L. S. Flannery (1983). "The management of end user computing." Communications of the ACM 26(10): 776-784.

	"End-user computing satisfaction is conceptualized as the affective attitude towards a specific computer application by someone who interacts with the application directly"	Doll, W. J. and G. Torkzadeh (1988). "The measurement of end-user computing satisfaction." MIS quarterly: 259-274.
End-user development (EUD)	"...users of software systems, who are acting as non-professional software developers, at some point to create, modify, or extend a software artifact"	Lieberman, H., Paternò, F., Klann, M., & Wulf, V. (2006). End-user development: An emerging paradigm: Springer.
Social studies	"who incorporate the results from research directly into an innovation"	Maclean, M., Anderson, J., & Martin, B. R. (1998). Identifying research priorities in public sector funding agencies: mapping science outputs on to user needs. Technology Analysis & Strategic Management, 10(2), 139-155.

Example of stakeholder definition

Field/scope	Definition	Reference
Business management		
Strategic management	"*The Wide Sense of Stakeholder:* Any identifiable group or individual who can affect the achievement of an organisation's objectives or who is affected by the achievement of an organisation's objectives. (Public interest groups, protest groups, government agencies, trade associations, competitors, unions, as well as employees, customer segments, shareowners, and others are stakeholders, in this sense.) *The Narrow Sense of Stakeholder:* Any identifiable group or individual on which the organisation is dependent for its continued survival. (Employees, customer segments, certain suppliers, key government agencies, shareowners, certain financial institutions, as well as others are all stakeholders in the narrow sense of the term.)"	Freeman, R. E. and D. Reed (1983). "Stockholders and stakeholders: A new perspective in corporate governance." California management review 25: 88-106.
	"A stakeholder in an organisation is any group or individual who can affect or is affected by the achievement of the organisation's objectives"	Freeman, R. E. (1984). "Strategic management." A Stakeholder Approach, Boston.
	"...who have ideas about what the economic and social performance of the enterprise should include."	Dill, W. R. (1975). "Public participation in corporate planning—strategic management in a Kibitzer's world." Long Range Planning 8(1): 57-63.

	"...a large array of actors who have an interest (stake) in the strategic future of the organisation..."	Eden, C. and F. Ackermann (2013). Making strategy: The journey of strategic management, SAGE.
Corporate social performance/corporate social responsibility/corporate social responsiveness	"persons or groups that have, or claim, ownership, rights, or interests in a corporation and its activities, past, present, or future"	Clarkson, M. E. (1995). "A stakeholder framework for analyzing and evaluating corporate social performance." Academy of management review 20(1): 92-117.
Finance/financial performance	"...stockholders and bondholders to include customers, suppliers, providers of complementary services and products, distributors, and employees." "...the firm as a contractual coalition that includes both investor and non-investor stakeholder…"	Cornell, B. and A. C. Shapiro (1987). "Corporate stakeholders and corporate finance." Financial management: 5-14.
Policy-making and governance		
	"...not only possess vital resources to realize policy goals and outcomes but also have different perceptions on the problem definition and have different information and ideas on solutions" "stakeholders include societal organisations, private parties, and organized and nonorganized citizens"	Edelenbos, J. and E.-H. Klijn (2006). "Managing stakeholder involvement in decision making: A comparative analysis of six interactive processes in the Netherlands." Journal of Public Administration Research and Theory 16(3): 417-446.
Natural and environmental studies		
Natural resource management/environmental resource management	"individuals, groups, and formal organisations who have a perceived interest or impact on a particular resource."	Selin, S. and D. Chevez (1995). "Developing a collaborative model for environmental planning and management." Environmental management 19(2): 189-195.
Natural resource management	"...any group of people, organised or unorganised, who share a common interest or stake in a particular issue or system; they can be	Grimble, R. and K. Wellard (1997). "Stakeholder methodologies in natural resource management: a review of

	at any level or position in society, from global, national and regional concerns down to the level of household or intra-household, and be groups of any size or aggregation."	principles, contexts, experiences and opportunities." Agricultural systems 55(2): 173-193.
	"…different interest groups involved in the utilization and conservation of natural resources…" "...cut across society as a whole and range, for example, from formal or informal groups of men or women farmers to government bodies or international agencies and multinational companies."	Grimble, R. (1998). "Stakeholder methodologies in natural resource management." Socio-economic Methodologies. Best Practice Guidelines. Chatham.
	"individuals who affect or are affected by certain decisions and actions (Freeman 1984). These individuals can be clustered into stakeholder categories according to their similarity in views, position(s) on an issue, and=or how they affect or are affected by the issue under discussion."	Prell, C., et al. (2009). "Stakeholder analysis and social network analysis in natural resource management." Society and Natural Resources 22(6): 501-518.
	"who is affected by the decisions and actions they take, and who has the power to influence their outcome"	Reed, M. S., et al. (2009). "Who's in and why? A typology of stakeholder analysis methods for natural resource management." Journal of environmental management 90(5): 1933-1949
Environmental policy development	"...for whom such policy is designed to provide benefits, and on whom it imposes constraints" "...a legislative body can be considered an 'organisation' whose 'customers' (stakeholders) will have 'needs' regarding the 'product' (viz., environmental policy)"	Altman, J. A. and E. Petkus Jr (1994). "Toward a stakeholder-based policy process: An application of the social marketing perspective to environmental policy development." Policy Sciences 27(1): 37-51.
Sustainability	"...who are all capable of inflicting unacceptable damage on the viability of the organisation if their interests are not met" "...actors that (i) provide essential means of	Garvare, R. and P. Johansson (2010). "Management for sustainability–a

	support required by an organisation; and (ii) could withdraw their support if their wants or expectations are not met, thus causing the organisation to fail, or inflicting unacceptable levels of damage"	stakeholder theory." Total Quality Management 21(7): 737-744.

Appendix III Participant's information sheet and consent form (English)

Cutting-Edge Approaches for Pollution Assessment in Cities (CAPACITIE)

End users and new pollution monitoring technologies

ABOUT THE PROJECT

CAPACITIE is a project funded by the European Commission within the 7th Framework Programme. It includes 12 PhD projects, and each of the projects is related to addressing a variety of issues linked to pollution monitoring in three cities: York (UK), Berlin (Germany) and Seoul (South Korea).

My research 'End users and new pollution monitoring technologies' is part of CAPACITIE, focusing on social science-based methods for understanding the needs of end users. The objective is to explore the expectation of users of monitoring data in the three cities, so that the deployment of new monitoring technologies can be better designed to meet the needs.

More information can be found at: www.capacitie.eu.

ABOUT THE INTERVIEW

Taking part in this interview is entirely voluntary. You are free to decline to take part in the project. You are free to decline to answer any questions and can withdraw from the conversation at any time without giving a reason. The interview will last approximately 30 minutes to an hour and it is fine to take a break at any time if you need to.

Following is a list of the topics which you will be asked about in the interview, so you know what to expect. However, please do not think you need to prepare for the interview.

I would like to know your personal perspective and experience about:

- The current city environment
- Scope of current legislation/environmental policy
- Policy-making process in your country/city

- Established measures / techniques regarding pollution monitoring in your city
- The development of monitoring techniques and future monitoring practice in your city

With your permission, I will record and take notes during the interview. The recording will be used for transcription purposes only. If you do not agree to being recorded, I will take notes only. If you agree to being recorded but feel uncomfortable at any time during the conversation, I will turn off the recorder at your request. The tape and transcription will be used for research purpose only.

Confidentiality

The regulations set out in the Data Protection Act 1998 of the British government will be followed in the research, which means that the recordings and the written transcripts of the interview will be stored securely at the University of York and only researchers who are directly involved in this project have access to them.

The outcome of the research will be published in reports and articles. These publications will include your opinions (might be short quotations), along with those of other interviewees, to support and illustrate the study results. However, your personal information will be kept strictly confidential, and anything that could identify you will not be included. These quotations will be anonymised so that you cannot be identified, unless you wish to be identified and authorise us to do so.

QUESTIONS OR PROBLEMS

Should you have any questions about the research or the interview, please feel free to contact Xiu Gao at Environment Department, University of York, UK, +44 1904 32 4093, xiu.gao@york.ac.uk.

Cutting-Edge Approaches for Pollution Assessment in Cities (CAPACITIE)

End users and new pollution monitoring technologies

CONSENT FORM

Please tick the boxes below as appropriate.

☐ I am willing to be interviewed about pollution monitoring of city environments.

☐ I understand what the project is about and what taking part involves.

☐ I understand that I do not have to take part in the interview and that if I do so, I can leave the conversation at any time without giving a reason.

☐ I understand that the information I share will be used to write reports or articles about pollution monitoring in cities. But my name will not be identified and that the information I share will not be given to anyone else, unless I give the permission.

☐ For any information about the project, I can contact Xiu Gao at Environment Department, University of York, UK, +44 1904 32 4093, xiu.gao@york.ac.uk.

[Choose one of the options that you prefer]

☐ I understand the interview will be recorded and the data will be stored securely at the University of York.

☐ I would like to participate in the interview without recording.

Name of participant: ______________________________

Signature of participant: ___________________________ Date: ____/____/________

Participant’s information sheet and consent form (German)

Cutting-Edge-Ansätze für Pollution Assessment in Städte (CAPACITIE)

Endanwender und neue Verschmutzung Monitoring-Technologien

ÜBER DAS PROJEKT

Capacitie ist ein von der Europäischen Kommission im Rahmen des 7. Rahmenprogramms geförderte Projekt. Es umfasst 12 PhD-Projekte, und jedes der Projekte im Zusammenhang mit einer Vielzahl von Fragen im Zusammenhang mit Überwachung der Luftverschmutzung in drei Städten zur Bewältigung von: York (UK), Berlin (Deutschland) und Seoul (Südkorea).

Meine Forschung ‘Endanwender und neue Verschmutzung Monitoring-Technologien’ ist Teil von capacitie, wobei der Schwerpunkt auf soziale wissenschaftlich fundierte Methoden für das Verständnis der Bedürfnisse der Endverbraucher. Das Ziel ist es, die Erwartungen der Nutzer von Monitoring-Daten in den drei Städten zu erkunden, so dass der Einsatz neuer Überwachungstechnologien können besser auf die Bedürfnisse zugeschnitten werden.

Weitere Informationen finden Sie unter www.capacitie.eu.

ÜBER DAS INTERVIEW

Teil in diesem Interview zu nehmen ist vollkommen freiwillig. Sie sind frei zu sinken an dem Projekt teil zu nehmen. Sie sind frei, alle Fragen zu beantworten, zu sinken und kann ohne Angabe von Gründen jederzeit aus dem Gespräch zurückziehen. Das Interview dauert etwa 30 Minuten bis eine Stunde dauern und es ist in Ordnung, eine Pause zu jeder Zeit in Anspruch nehmen, wenn Sie benötigen.

Es folgt eine Liste der Themen, die Sie in dem Interview gefragt werden, so dass Sie wissen, was zu erwarten ist. Aber bitte nicht denken, Sie für das Gespräch vorbereiten müssen.

Ich möchte Ihre persönliche Perspektive und Erfahrung zu wissen über:

• Die aktuelle Stadt-Umgebung

• Umfang der geltenden Gesetzgebung / Umweltpolitik

• politischen Entscheidungsprozess in Ihrem Land / Stadt

• Etablierte Maßnahmen / Techniken in Bezug auf Überwachung der Luftverschmutzung in der Stadt

• Die Entwicklung von Überwachungstechniken und die künftige Überwachung der Praxis in Ihrer Stadt

Mit Ihrer Erlaubnis werde ich Notizen während des Interviews aufzuzeichnen und zu nehmen. Die Aufnahme wird nur für Transkriptionszwecke verwendet werden. Wenn Sie aufgezeichnet nicht einverstanden sind, werde ich Notizen nur nehmen. Wenn Sie aufgezeichnet, sondern fühlen sich unwohl zu jeder Zeit während des Gesprächs einverstanden sind, werde ich den Recorder auf Wunsch deaktivieren. Das Band und die Transkription wird nur für die Forschung verwendet werden.

Vertraulichkeit

Die Regelungen des Datenschutzgesetz festgelegten 1998 von der britischen Regierung wird in der Forschung verfolgt werden, was bedeutet, dass die Aufnahmen und die schriftlichen Transkripte des Interviews wird an der Universität von York sicher gespeichert werden und nur Forscher, die direkt beteiligt sind, in dieses Projekt haben Zugang zu ihnen.

Das Ergebnis der Forschung werden in Berichten und Artikeln veröffentlicht. Diese Veröffentlichungen gehören Ihre Meinungen (möglicherweise kurze Zitate sein), zusammen mit denen anderer Interviewpartner zu unterstützen und die Ergebnisse der Studie zeigen. Allerdings werden Ihre persönlichen Daten streng vertraulich behandelt werden, und alles, was Sie identifizieren könnten, werden nicht einbezogen werden. Diese Zitate werden anonymisiert werden, so dass Sie nicht identifiziert werden, es sei denn, Sie zu identifizieren wollen und ermächtigen uns, dies zu tun.

FRAGEN ODER PROBLEME

Sollten Sie Fragen über die Forschung oder das Interview haben, wenden Sie sich Xiu Gao an Environment Department, University of York, UK, +44 1904 32 4093, xiu.gao@york.ac.uk zu kontaktieren.

Innovative Lösungsansätze zur Einschätzung von Umweltverschmutzung in Städten

(CAPACITIE)

Endverbraucher und neue Technologien

EINVERSTÄNDNISERKLÄRUNG

Bitte kreuzen Sie die zutreffenden Felder unten an.

☐ Ich bin damit einverstanden zur Überwachung von Umweltverschmutzung in Städten befragt zu werden.

☐ Ich verstehe das Grundprinzip des Projekts und was meine Teilnahme bedingt.

☐ Ich verstehe, dass meine Teilnahme an diesem Gespräch freiwillig ist und ich das Gespräch jederzeit ohne Angabe von Gründen verlassen kann.

☐ Ich verstehe, dass meine Angaben zur Anfertigung von Artikeln oder Berichten über die Überwachung von Umweltverschmutzung in Städten verwendet werden. Mein Name wird nicht verwendet und meine Informationen werdem nicht an Dritte weitergegeben, ausser ich gebe dafür meine ausdrückliche Erlaubnis.

☐ Für weitere Informationen über das Projekt, kann ich mich an Xiu Gao wenden, in der Umweltabteilung , University of York, UK, +44 1904 32 4093, xiu.gao@york.ac.uk.

[Bitte wählen Sie die bevorzugte Option]

☐ Ich verstehe, dass das Interview aufgezeichnet wird und die Daten sicher an der University of York aufbewahrt werden.

☐ Ich möchte an dem Interview ohne Tonaufnahme teilnehmen.

Name des Teilnehmers:______________________________

Unterschrift: ___________________________ Datum: ____/____/________

Participant's information sheet and consent form (Korean)

도시환경 오염평가를 위한 첨단 기법 (CAPACITIE) 연구:

최신 환경오염 모니터링 기술의 수요자 인식조사

Cutting-Edge Approaches for Pollution Assessment in Cities (CAPACITIE):

End users and new pollution monitoring technologies

연구 과제

본 연구 과제 '최신 환경오염 모니터링 기술의 수요자 인식조사(End users and new pollution technologies)'는 유럽연합 제7차Framework Programme이 지원하는 '도시환경 오염평가를 위한 첨단 기법(CAPACITIE) 연구의 일환으로, 사회과학적 조사기법에 의거한 관련 수요자 인식 조사를 수행하고 있습니다. 본 연구는 서울 및 영국의 요크(York), 독일의 베를린(Berlin) 세 도시의 환경오염 모니터링 자료 수요자들의 요구를 파악하여 보다 적합한 최신 환경오염 모니터링 기술을 고안하는데 이를 궁극적으로 활용하고자 하며, 이에 연구자는 관련 기관 전문가 및 수요자들의 의견을 구하고자 합니다.

인터뷰

본 인터뷰는 자발적 참여에 의해 이루어지며, 연구자는 응답자의 연구과제 참여의사 및 질문에 대한 응답여부 결정을 존중합니다. 연구자의 인터뷰는 약 30분간 진행될 예정이며 (통역이 필요한 경우 1시간 소요), 인터뷰 예상 질문은 다음과 같습니다.

- 거주/관할 시의 환경 및 환경오염 실태
- 거주/관할 시의 환경 관련 법률 제정 및 정책 입안 현황

- 거주/관할 시의 정책 입안 절차
- 거주/관할 시의 사용중인 환경오염 모니터링 기술 및 방법
- 거주/관할 시의 환경오염 모니터링 기술 개발 및 이용 계획

응답자의 허가에 따라, 본 인터뷰 내용은 연구자에 의해 기록 및 녹음되어 연구목적으로만 사용될 예정입니다. 응답자는 인터뷰 전과 진행 중 언제든지 연구자에게 녹음을 불허하거나 중지 요청할 수 있으며, 연구자는 응답자의 이와 같은 요청을 존중하여 전 인터뷰를 진행합니다.

연구 정보 기밀 유지

영국 정부의 정보 보호 협약(Data Protection Act, 1998)에 따라, 본 연구에 사용된 인터뷰 녹음 파일과 기록은 요크대학에 안전하게 보관될 것이며 본 과제의 연구자 외 접근을 제한합니다. 연구 결과는 보고서와 논문을 통해 발표될 예정이며, 응답자의 응답 내용이 인용될 수 있습니다. 응답 내용은 연구 목적으로만 사용될 것이며 응답자의 개인 정보 혹은 응답자를 식별할 수 있는 정보는 기밀로 유지될 것입니다.

관련 문의

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capacitie

UNIVERSITY *of York*

도시환경 오염평가를 위한 첨단 기법 (CAPACITIE):

최신 환경오염 모니터링 기술의 수요자 인식조사

연구 정보 제공 및 활용 동의서

응답자는 다음 사항들을 확인하고 해당 사항에 표시하여 주시기 바랍니다.

□ 응답자는 도시 환경오염 모니터링과 관련한 인터뷰에 동의합니다.

□ 응답자는 연구과제 참여 및 역할에 대해 이해 하였습니다.

□ 응답자는 본 인터뷰에 자발적으로 참여 하였습니다.

□ 응답자는 제공한 정보 활용 및 기밀 유지에 대한 안내를 받았습니다.

□ 응답자는 연구자에게 해당 연구 과제에 대한 정보를 문의할 수 있었습니다.

[해당 사항만 선택]

□ 응답자는 응답 내용이 녹음되는 것에 동의합니다.

□ 응답자는 응답 내용을 녹음하지 않고 응답하는 것에 동의합니다.

응답자:______________________(서 명)

날짜: ____/____/________

Appendix IV Interview topic guide

Cutting-Edge Approaches for Pollution Assessment in Cities (CAPACITIE)

End users and new pollution monitoring technologies

TOPIC GUIDE

Introduce the project and the interview

Ask for consent before start

PART 1. INTRODUCTION

1. Can you tell me a bit about yourself?

PROBE: How long have you been working in the field?

What do you know about environmental monitoring?

What is your involvement in environmental regulations specifically?

PART 2. VIEWS OF CURRENT LEGISLATION AND EXPECTATIONS

2. Can you give me a sense of your perspective on the current city's environment?

PROBE: Which aspects are good and which are bad? Air quality, water quality, noise or others?

How has it changed in the past 10 years? If yes, why?

Which pollution bothers people the most in the city? Any difference geographically?

Why is it considered the most significant pollution problem? (the impacts)

If you had to rank order the remaining environmental issues what would come next?

What are the sources of the pollution? And what are the pollutants?

How do you explain the concerns?

3. Are these aspects all covered in the current legislation?

PROBE: Does the most significant one receive more attention in the environmental policies (priority pollution type)?

4. How does the policy-making process work?

PROBE: Could you give me any example? (At national level or local level)

Who are the key actors involved in policy making?

Aside from the example, how does it work at national/local level (if example is at local/national level)?

How long does it take before a new legislation/regulation/standard becomes effective?

Who are consulted if the legislative measure is carried out at local level?

5. In what way is the current legislation effective or not effective in managing the environment? Could you give me any example?

PROBE: Aside from the example, how is it working on the other issues?

What resource would benefit the implementation? And who should be responsible for that?

6. There are discussions about non-regulatory pollutants and emerging contaminants, do you think that there is any need for environmental legislation to change to meet the arising concerns?

PROBE: What is your opinion on the research or discussion on non-regulatory pollutants or emerging contaminants?

In what way do you think the scientific knowledge can influence the policy-making?

<u>PART3 ENVIRONMENTAL MONITORING</u>

7. What environmental aspects are monitored to your knowledge? How do you know?

PROBE: Where can you get the monitoring results? Do you think it is easy to access?

What is the main reason that you need to access the environmental monitoring data?

Who are monitoring the environmental quality?

8. Do you know what measures or techniques of pollution monitoring have been implemented?

PROBE: Have you noticed any change over the past few years regarding monitoring techniques? Can you give any description? From where did you see the changes?

What do you think that drives the change/development?

9. How does the current environmental monitoring technology support the meeting of emission requirements?

PROBE: Is there any extra data/parameter that you would like to get from the monitoring techniques if possible?

In case of 'yes': Why do you prefer to have the extra data?

To whom you need to send the extra data?

In your opinion, will new technologies be helpful? In what way?

In case of 'no': why? who is benefiting from the data you gathered?

In what way? (raw data or reports, how and how often?)

10. Imagine we are going to develop a new generation of environmental monitoring techniques in the future, what do you think about the trend of technological development (presenting pictures)?

PROBE: Could it better support your work?

What improvements would you like to see, if any? Why?

How could the design be improved from your viewpoint?

What are the costs or benefits to you?

Who else do you think can benefit from the new techniques? How?

What is your opinion about the future environmental monitoring in general? Who should take the lead? (the government, the industry, or the society?)

PART 4 CONCLUSION OF INTERVIEW

11. Do you want to add anything on environmental policies and pollution monitoring issues?

Closing: Given the topics of the research and the issues that have come up in our conversation, are there any other people that you would suggest I talk to?


Self-Testing
Noise Sensor
Network Node

Appendix V List of interview participants by code, date and interview method

City	Interviewee code	Interview date	Interview method
York, UK	Interviewee_Y1	10/08/2015	Face-to-face
	Interviewee_Y2	28/08/2015	Face-to-face
	Interviewee_Y3	01/09/2015	Face-to-face
	Interviewee_Y4	10/09/2015	Face-to-face
	Interviewee_Y5	14/09/2015	Face-to-face
	Interviewee_Y6	16/09/2015	Face-to-face
	Interviewee_Y7	18/09/2015	Face-to-face
	Interviewee_Y8	24/09/2015	Face-to-face
	Interviewee_Y9	24/09/2015	Face-to-face
	Interviewee_Y10	13/10/2015	Face-to-face
	Interviewee_Y11	21/10/2015	Face-to-face
	Interviewee_Y12	21/10/2015	
	Interviewee_Y13	26/10/2015	Skype
	Interviewee_Y14	05/02/2016	Face-to-face
	Interviewee_Y15	17/03/2016	Face-to-face
	Interviewee_Y16	20/05/2016	Phone
	Interviewee_Y17	01/06/2016	Face-to-face
Berlin, Germany	Interviewee_B1	07/07/2016	Face-to-face
	Interviewee_B2	08/07/2016	Face-to-face
	Interviewee_B3	13/07/2016	Face-to-face
	Interviewee_B4	13/07/2016	
	Interviewee_B5	13/07/2016	

	Interviewee_B6	26/07/2016	Face-to-face
	Interviewee_B7	27/07/2016	Face-to-face
	Interviewee_B8	27/07/2016	
	Interviewee_B9	28/07/2016	Face-to-face
	Interviewee_B10	28/07/2016	Face-to-face
	Interviewee_B11	29/07/2016	Face-to-face
	Interviewee_B12	02/08/2016	Face-to-face
	Interviewee_B13	15/08/2016	Skype
	Interviewee_B14	16, 21/06/2016	Email
Seoul, South Korea	Interviewee_S1	02//11/2015	Face-to-face
	Interviewee_S2	04/11/2015	Face-to-face
	Interviewee_S3	04/11/2015	Face-to-face
	Interviewee_S4	05/11/2015	Face-to-face
	Interviewee_S5	06/11/2015	Face-to-face
	Interviewee_S6	10/11/2015	Face-to-face
	Interviewee_S7	10/11/2015	Face-to-face
	Interviewee_S8	10/11/2015	
	Interviewee_S9	10/11/2015	
	Interviewee_S10	25/07/2016	Face-to-face

Appendix VI EU air quality limit values and UK air quality objectives as in UK National Air Quality Strategy (2007) (PM and NO_2)

National air quality objectives and European Directive limit and target values for the protection of human health

Pollutant	Applies	Objective	Concentration measured as[10]	Date to be achieved by and maintained thereafter	European obligations	Date to be achieved by and maintained thereafter	New or existing
Particles (PM_{10})	UK	50μg.m^{-3} not to be exceeded more than 35 times a year	24 hour mean	31 December 2004	50μg.m^{-3} not to be exceeded more than 35 times a year	1 January 2005	Retain existing
	UK	40μg.m^{-3}	annual mean	31 December 2004	40μg.m^{-3}	1 January 2005	
	Indicative 2010 objectives for PM_{10} (from the 2000 Strategy and 2003 Addendum) have been replaced by an exposure reduction approach for $PM_{2.5}$ (except in Scotland – see below)						
	Scotland	50μg.m^{-3} not to be exceeded more than 7 times a year	24 hour mean	31 December 2010			Retain existing
	Scotland	18μg.m^{-3}	annual mean	31 December 2010			
Particles ($PM_{2.5}$) Exposure Reduction	UK (except Scotland)	25μg.m^{-3}	annual mean	2020	Target value 25μg.m^{-3} [12]	2010	New (European obligations still under negotiation)
	Scotland	12μg.m^{-3}		2020	Limit value 25μg.m^{-3}	2015	
	UK urban areas	Target of 15% reduction in concentrations at urban background[11]		Between 2010 and 2020	Target of 20% reduction in concentrations at urban background	Between 2010 and 2020	
Nitrogen dioxide	UK	200μg.m^{-3} not to be exceeded more than 18 times a year	1 hour mean	31 December 2005	200μg.m^{-3} not to be exceeded more than 18 times a year	1 January 2010	Retain existing
	UK	40μg.m^{-3}	annual mean	31 December 2005	40μg.m^{-3}	1 January 2010	
Ozone	UK	100μg.m^{-3} not to be exceeded more than 10 times a year	8 hour mean	31 December 2005	Target of 120μg.m^{-3} not to be exceeded more than 25 times a year averaged over 3 years	31 December 2010	Retain existing

Appendix VII Description of grounded theory themes from three case studies

Theme	Contents
State and progress	• Policy development and progress of the air quality agenda • Emission control policies (especially transportation) • Political system and organisations with respect to the monitoring and management of air quality • Perceptions of the development of monitoring techniques • Use of generated air quality data and information provision
Awareness and willingness	• Knowledge of the availability of air quality information channel and how that information is perceived • Understanding the adverse impacts of air pollution and willingness to change behaviour • Policy priority and political will to tackle air pollution • Awareness of self-responsibility • Awareness of administrative and social barriers
Power and influence	• Possession of resources which are needed to establish air-quality monitoring practice and implement control measures • Legitimacy and political influence with respect to local air quality management • Development and challenges in terms of taking up new monitoring technologies • How the impacts of non-regulatory monitoring are perceived and what interests do end-user stakeholders have • Engagement in cross-government and intergovernmental collaboration
Responsibility	• Possession of resources which are needed to monitor and/or improve air quality • Distribution of impacts and accountability of the management organisation • Scales of responsibility due to the impacts of air pollution (for example, local or national, personal) • Types of responsibility (legal or ethical) • Distribution of responsibility for data management
Technology innovation	• Availability and features of non-regulatory air quality sensing technique • Concerns about the challenges of the innovation • Potential functions, cost and benefits • Forms of information provision

CO	Carbon monoxide
CO_2	Carbon dioxide
NO	Nitric oxide
NO_2	Nitrogen dioxide
NOx	Nitrogen oxides (NO + NO_2)
PAHs	Polycyclic aromatic hydrocarbons
PM	Particulate matter
PM_{10}	Particulate matter <10µm
$PM_{2.5}$	Particulate matter <2.5µm
SOx	Sulphur oxides
SO_2	Sulphur dioxide
O_3	Ozone
VOCs	Volatile organic compounds
µg/m3	microgram (one millionth of a gram) per cubic metre
km	kilometre
ppb	parts per billion (parts per 1000 million)

ACEA	European Automobile Manufacturers' Association (EU)
AQAP	Air Quality Action Plan (UK)
AQEG	Air Quality Expert Group (UK)
AQMA	Air Quality Management Area (UK)
AURN	Automatic Urban and Rural Network (UK)
CAC	Clean Air Conservation Act (South Korea)

CYC	City of York Council (York, UK)
CSP	Corporate Social Performance
CSR	Corporate Social Responsibility, Corporate Social Responsiveness
Defra	Department for Environment, Food and Rural Affairs (UK)
DfT	Department for Transport (UK)
EU	European Union
EUC	End-user Computing
EUD	End-user Development
EUP	End-user Programming
GDP	Gross Domestic Product
GEMS/AIR	Global Environmental Monitoring System for Air Pollution (GEMS/AIR)
GPK	Green Party Korea (South Korea)
GT	Grounded Theory
IPCC	Intergovernmental Panel on Climate Change
K-eco	Korea Environmental Corporation (South Korea)
LAQM	Local Air Quality Management (UK)
LES	Low Emission Strategy (York, UK)
LEZ	Low Emission Zones
MEA	Multilateral Environmental Agreement
NAMIS	National Ambient Air Monitoring Information System (South Korea)
NEC	National Emission Ceilings Directive 2016/2284/EU (EU)
NGO	Non-Government Organisation
NIER	National Institute of Environmental Research
NIMBY	Not- In-My-Backyard
OEM	Original Equipment Manufacturers
OECD	Organisation for Economic Co-operation and Development

QA/QC	Quality Assurance and Quality Control
RDE	Real Driving Emission
R&D	Research and Development
SMA	Seoul Metropolitan Area (South Korea)
SMG	Seoul Metropolitan Government (Seoul, South Korea)
SPD	Social Democratic Party of Germany (Germany)
TEMM	Tripartite Environment Ministers Meeting (South Korea, Japan and China)
UNECE	United Nations Economic Commission for Europe
WHO	World Health Organisation
WWF	World Wide Fund for Nature

Currency conversion

1 Euro = 1.2 US Dollar

1 US Dollar = 1070 South Korean Won

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