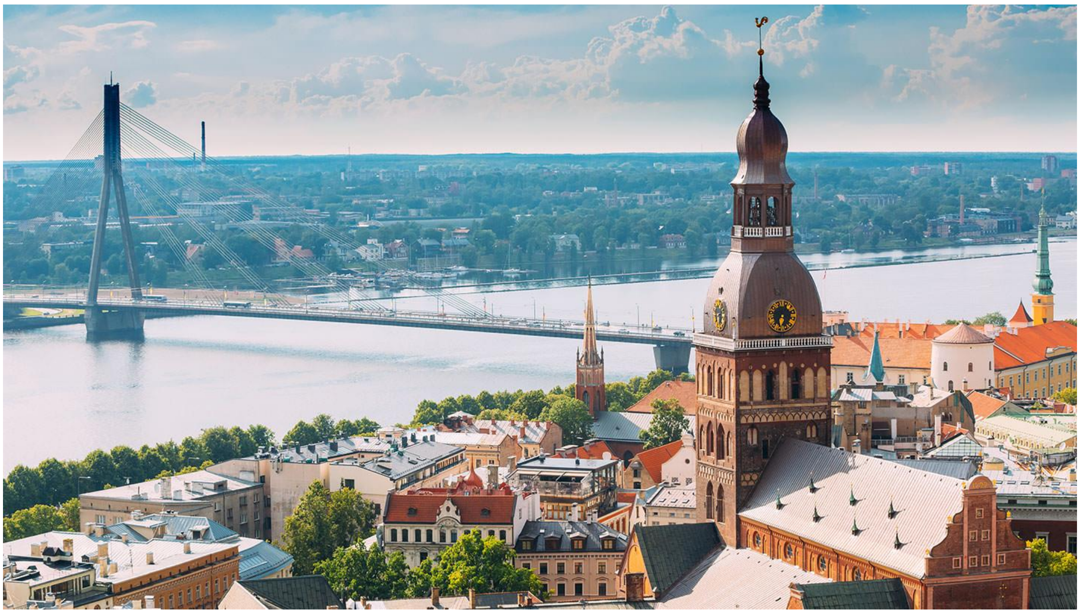
European Association of Remote Sensing Companies

Sentinels Benefits Study (SeBS)

A Case Study

on

Air Quality Forecasting in Latvia



Client:	ESA
Client Representative:	Alessandra Tassa
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Author(s):	Geoff Sawyer (EARSC)
	Nikolay Khabarov (IIASA)
Reviewer	Alessandra Tassa (ESA)

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or more information contact:

- **EARSC: info@earsc.org**
- **ESA: Alessandra.Tassa@esa.int**

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Setting the Scene

It was a cold March morning when Anna pressed the button on the traffic lights to request to cross the road. As she did so, a lorry thundered past putting out clouds of black exhaust. She coughed. The lights changed and she looked carefully before crossing the road. Even if the lights were green for her, her grandmother had always insisted that she should not take a chance as a driver might have been distracted and not seen the red light.

She hurried on down the street and turned into the courtyard of an apartment block. Anna opened the door with her key and climbed up the two flights of stairs to her grandmother's home. Nanny Greta lived on the second floor where she had a nice view overlooking the park. When the weather was fine and the traffic was not too noisy, she would sit on her balcony watching the children play in their playground and the mothers chatting around the edge as they did so. She regretted that the road between her front door and the park had become so busy over the last few years as a result of the the new biomass power plant and the many lorries passing by carrying wood chips.

Anna entered her nan's apartment and was greeted with a kiss on each cheek. They sat down at each end of the sofa and started to catch up with their news. Anna started by saying that she had found her first job as a research assistant at the University. She would be working to understand what triggers asthma in young children.

When asked how she was, Greta replied that she was fine and apart from all the usual aches and pains there was nothing wrong with her. But she went on to say that she had been out to the shop earlier to get some things for their lunch and had run out of breath when climbing back up the stairs. She had paused on the first landing to recover her breath. It was nothing to worry about, but it was the first time she had felt this bad.

Anna took out her phone and started to play with it. After a moment she turned to her nan and showed her the screen. "Maybe this is why you felt bad this morning, the air quality alert is set at red". Greta was mystified, "what does that mean?" she asked Anna, "what has that to do with me having to pause whilst climbing the stairs?"

Anna explained that the red alert means that the air quality today is poor in the area around Greta's apartment. Worse, it is forecast to be like this for the next 2 days as well. For someone like her Nan, who has had bouts of asthma in the past, it shows that they are at risk and should avoid unnecessary activities in the riskiest areas. The lorries passing along the main road were throwing out exhaust containing many particles which floated in the air. The cars and buses were adding to this through brake dust as well as exhaust fumes. As the snow and ice melted, salt and sand put down to help keep the roads clear was also being thrown up into the air. The particles could provoke severe asthma attacks in some people and hence the red alert.

Anna took her nan's phone, here, let me install the app so that you can see the forecasts yourself. That way, if it is red, you can maybe plan not to go out or to take it easy. At least you will know what may be causing it. In any case, I think you should go and see your doctor to see what she thinks.

A few days later, Anna had a call from her Nan. The doctor said that I have nothing to worry about, but she was very impressed that I had the app. She thinks it is excellent and, if possible, that I should simply avoid going out when the forecast is red. It is after all only a few days each year but that on those days, if I go out, I risk provoking an attack which could lead me to end up in hospital. Using the app should help me to avoid that.

She ended by saying, "I am going to tell everyone in my choir about it. Many of the singers are asthmatic and on some days they cannot sing. If it can help them avoid ending up in hospital it is better for everyone."

This story to set the scene for the case, is entirely imaginary, although realistic based on our knowledge gained through the case interviews. The places are real, although the characters, the conversation and the situation are entirely fictional.

Executive Summary

> *Clean air is vital for people - if a person can live without food for 40 days, without drinking - for 3 days, then he will not be without air for even 3 minutes. Where in a city can you get fresh air? Parks? Urban green areas and forests? Not always. The economic activity of the city and the active flow of transport on the main transport arteries on days with a slight wind and temperature inversion cause the accumulation and spread of pollution throughout the city*[1]*.*

Air pollution is one of the greatest threats to human health. Breathing polluted air increases the risk of debilitating illness and fatal diseases such as lung cancer, heart disease and strokes. Globally, it is now the 4th highest fatal risk factor causing 6.7m premature deaths each year.

Air pollution is most severe in urban areas where people are living in close proximity and houses, offices and transport are at their most dense. Many cities are transport hubs with airports and ports which further contribute to the problem as do the buildings which reduce and change airflows. But air pollution is not restricted to cities and even low levels in the countryside can increase the risk of illness and death in vulnerable persons.

In Europe, pollution levels have been falling following stringent efforts particularly in urban areas. The use of wood and coal for domestic heating has been outlawed in many cities, which are also limiting access to the most polluting cars and lorries. Furthermore, legislation is favouring the phasing out of thermic engines in favour of the introduction of electric vehicles. The overall goal being to reduce emissions, particularly of small particles, of nitrous oxides and ozone.

Not all sources are man-made nor can be controlled locally. Farming creates dust containing traces of chemicals used on crops, wildfires and volcanos which create smoke particles whilst storms can lift sand into the upper atmosphere which then descends on countries far away.

According to the European Environment Agency, in 2019, 307,000 premature deaths in Europe are attributed to small particles with 640,000 deaths overall due to all forms of ambient (exterior) air pollution[2]. Whilst these numbers are high, they still indicate a significant reduction of over 20% since 2005 and the EU goal is to reduce this further, by imposing stricter limits, to around 200,000 deaths by 2030 so reducing the number of early deaths by 55% compared to 2005.

According to the World Bank and the IHME[3], premature deaths caused by polluted air, cost the world economy $225billion each year and taking all consequences into account, is about $5.1trillion worldwide. Within these numbers, the UK, is estimated to have 19,800 premature deaths each year and in Latvia the figure is around 1,400 deaths attributed to air pollution.

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[1] Adapted from the introduction on the Riga City website.

[2] EEA report on Health Impacts of Air Pollution.

[3] The cost of Air Pollution (World Bank and IHME). Note, that these figures differ from those available in the UK (for example through COMEAP) but we shall use them for comparison with Latvia.

Whilst the links between air pollution and health risks are well-established, the precise relationships are poorly understood. Some things are known about air pollution i.e. mortality rates, latency and cessation lag, but a lot is unknown. It is well established that there is some immediate effect on death rates in the days immediately following higher or lower air pollution levels; these are the effects detected by time-series studies. However, most of the mortality effects of air pollution take longer to occur[4], and the increased life-time risk to an individual is hard to quantify.

Air pollution is not binary; it is not the case that below a certain threshold the risk becomes zero. Each person inhales 14 kg of air each day, while drinking just 2 kg of water and eating 1.5 kg of food. Air is therefore an essential component for life and, with each breath, particles in that air enter the body but affect each person differently. Research shows that not only acute events but also chronic exposure, affects human health and reduces human life expectancy by more than eight months on average and by more than two years in the most polluted cities and regions worldwide.

Much of the risk is down to individual health. For example, it is known that air pollution can be a trigger for asthmatic attacks which in rare cases can lead to death. This was the case in London in 2013 when sadly a 9-year-old girl died (see Ella's Story in the report). Some people are more susceptible than others. Hence, systems which provide information on the current levels of air pollution and, perhaps more importantly alerts can empower people. Specifically, those who have health issues aggravated by pollution can take precautionary actions by staying inside, avoiding the worst affected areas and to avoid unnecessary physical activities on the worst days.

The *airTEXT* system was first introduced into some London boroughs in 2007 and has been extended to cover the whole of London and more recently, Manchester. In 2018, it has also been introduced into Latvia, in the capital city Riga as Riga *airTEXT*. The service works based on data coming from the Copernicus Atmosphere Monitoring service (CAMS) operated by the ECMWF. CAMS is based around the ECMWF Integrated Forecasting System (IFS) which is a complex model taking in data from many different sources around the world. Among its many data sources, Sentinel satellites provide information on the atmosphere and land and ocean surfaces which influence the earth atmosphere.

Cambridge Environmental Research Consultants (CERC), a company based in Cambridge UK, takes this data and merges it with another model (ADMS-Urban) which define local emissions and urban structures. The model is adapted to each implementation of *airTEXT* to simulate the roads, buildings and pollution sources and to analyse the change in airflows. in each city concerned. Our case looks at the impact in Riga but also in London as having the longest experience of its operation.

The system is relatively new but reports from both London and Riga are positive about its use. It is a tool to help vulnerable citizens to avoid suffering and allows them to plan a healthier use of their time. Driven by increased awareness of the problem and heightened concerns by citizens, city administrators have developed the system progressively using also the information it provides to drive relevant policy decisions. As a result, it can help to reduce the number of hospital admissions,

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[4] The Mortality effects of long-term exposure to particulate air pollution in the UK. Report by COMEAP. Pp58

reduce working days lost, and in the extreme, reduce premature deaths. The economic case shows a potential benefit stemming from the use of Sentinel data, of €175k to Riga and €3.8m in the UK, but much, much more importantly a better quality of life for its citizens.

Air pollution does not stop at country borders and the Sentinel data as well as the CAMS data does not either. If we take the Latvia and UK numbers and scale to the whole of Europe, we estimate a total benefit of around €30m.

These figures are certainly underestimates. Digital information on air quality is becoming more widely available. In the last few years, weather forecasts, available on people's phones or laptops, have generated much more sophisticated behaviour with decisions on what to do and when to do it directly affected by the weather forecast. More accurate forecasts have led to greater certainty for longer periods in the future. People use this data to plan their leisure activities so, for example, avoiding going to the beach when rain is forecast. Most of the population are regular users of weather forecasts even to the extent that they become dependent upon it.

This has a positive effect on their lives for which we have no measure. A similar result is to be expected once air quality data reaches similar levels of availability and reliability. Furthermore, as new satellites and measurement instruments are launched, the quality and reliability are expected to dramatically improve, allowing each citizen a more informed choice whilst protecting their health.

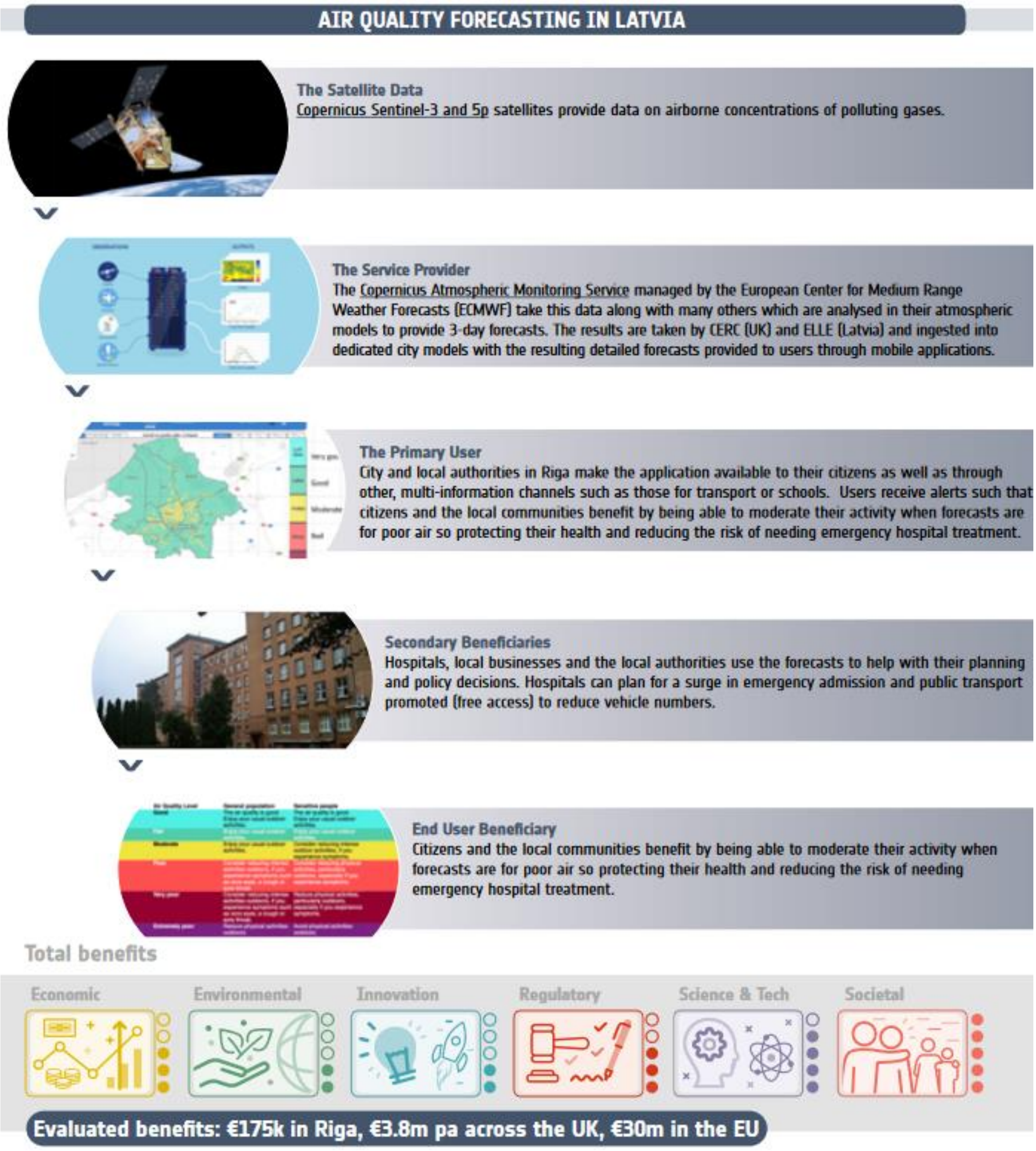

Figure 1: Summary of Benefits along the Value Chain

1 Introduction & Scope

1.1 The Context of this study

The analysis of the case study *Air Quality in Latvia* is carried out in the context of the 'The Sentinel Economic Benefits Study' (SeBS). This study is looking to develop cases showing how EO-derived products based on data generated by one or more Sentinel satellites deliver value to society and citizens. The Sentinel satellites form a crucial part of EU's Copernicus Programme, providing space-based observations on a full, free and open basis. Data coming from the Sentinels – together with other data collected by contributing missions and ground, sea or airborne instruments – is used to support key economic or societal areas such as agriculture, insurance, disaster management, climate change monitoring, etc. Sentinel data are thus a key component of the Copernicus Services, and a crucial source used by companies to deliver products and services helping different users across the Globe.

1.2 What is the Case all about?

This case is about the use of data from Sentinel 3 and that coming from the Copernicus Atmosphere Service (CAMS) to provide information on air quality to the citizens of Riga in Latvia and in London UK. The data, when coupled with a model of the local urban environment; mapping the streets, transport routes and densities, local infrastructure and high emission sources, allows a map of forecast air pollution to be generated and provide guidance of exposure to local citizens. The information is made available through a service called *airTEXT*.

The core use is by individuals, especially those with health problems, who may decide to adapt their behaviour on days where the pollution is high. They can choose to avoid exposure and as a result reduce their own risk of becoming ill, requiring urgent treatment or worse an early death.

This has a number of benefits:

- It allows individuals with health problems to avoid exposure on bad pollution days and hence to reduce the risk of adverse health effects.
- It reduces the load on local hospitals for urgent admissions and enables load planning when pollution peaks are forecast.
- It allows local businesses and public services to adjust their operations especially where children may be concerned.
- It helps local administrators to introduce legislation or procedures which reduce the overall pollution levels.
- It raises awareness of the problems associated with air pollution and helps drive political action.

Our case focuses on Riga *airTEXT* as it is operated in Riga, Latvia but also with reference to London where it was first installed, and more data is available in which case, the service is referred to as *airTEXT* to differentiate it.

1.3 How does this case relate to others?

This case is quite different from others from the perspective of the data used and the way the service is generated and used. It differs in the nature of the value chain and the role of the primary users - who are fundamental to our analyses.

From a methodological perspective, we hesitated before taking on this case due to two factors:

1. The service is using data coming from many sources which is processed by several models to generate the information output. Hence the attribution to Sentinels was expected to be quite difficult. In practise, the importance of the data coming from the Sentinels is very high and hence attribution has been judged as 100%, but against conservative economic benefit estimates.
2. Calculating the economic benefits was expected to be complex even without the problem of attribution. However, several organisations have made efforts to calculate the benefits in monetary terms and we have been able to benefit from these.

However, in comparison with other cases, the value chain which we use at the core of our methodology is quite different in the roles being played and does not result in progressive transformations of the information at each of the tiers. Whilst the service (*airTEXT*) is clear, the resulting information is essentially passed directly to citizens. It is enabled by the primary users and other stakeholders, but there is no transformation by the primary user and subsequently by other secondary beneficiaries. Instead, the service is constructed by the service provider, in line with needs expressed by primary users before being delivered directly to the end users, the citizens. Other, secondary beneficiaries use the service much as would a citizen and they may even specify their own preferences for the style and presentation of the service in the same way as the primary user. Consequently, unlike all other cases so far, there is not a visible benefit at each tier. The benefits are considered to be societal and derived from statistical trends.

As a result, the economic benefits have been calculated at a societal level and are not assigned to separate tiers of the value chain as in all other cases we have produced.

In compensation, the non-economic benefits were expected to be clearer and hence the overall story would be strong. In reality, neither of these factors has proven too difficult to address, whilst the story is certainly very strong and interesting!

airTEXT has some common features with water quality monitoring. In two cases on this topic, we have found that in Germany and in Finland, public bodies are providing information on lake water quality and enabling their citizens to decide whether the lake is safe for swimming or not. In this respect, these the cases for air and water are similar in that the public bodies concerned do not have a legal requirement to provide the information (although this can be debated) but nevertheless, they make a certain budget available so as to provide a better service to their citizens.

1.4 More about the Study

Each case study analysed in SEBS, focuses on products and services which use data coming from Sentinel satellites, measuring the impact of that product or service throughout the value chain. The starting point is the primary user of the satellite data, followed by a step-by-step analysis whereby the operations of beneficiaries in each subsequent link of the value chain are analysed, all the way down to citizens and society.

In this process, the main aim is to understand and demonstrate the value which is generated using satellite-based Earth Observations (EO) and particularly the data coming from the Copernicus Sentinel satellites. Each case study thus underlines the causal relationship between the use of Copernicus Sentinel satellite data and benefits resulting from their use, including increased productivity, more efficient and environmentally friendly operations, economic gains and improved quality of life, among others.

The benefits are categorised into 6 dimensions of which 5 are non-monetary. In our work we have found that often the non-monetary benefits are strongly under-appreciated even if most people's immediate response is to look for hard numbers. The 6 dimensions of value are: economic, environmental, regulatory, innovation & entrepreneurship, science and research, social benefits. More details on these and the methodology can be found in a dedicated report[5].

The evaluated and demonstrated benefits can be used by:

- **Decision makers**: Having access to a portfolio of concrete cases where the benefits from the operational use of Sentinel data in decision making are clearly articulated, helps decision makers not only to justify future investments but also to direct them towards areas that most matter in their country or organisation.
- **Users:** Moving beyond a vague idea of how EO services can support more effective operations requires a concrete understanding of the benefits they can actually bring in similar cases. In this regard, it is both numbers and stories that can resonate with users and attract them to explore further or deeper uses of EO in their operational activities.
- **Service providers:** Solid argumentation around the economic and environmental benefits stemming from the use of EO, coupled with powerful storytelling, can become an effective marketing tool for service providers seeking to promote their solutions and for EARSC to promote the sector.

In the framework of this project, over 25 case studies will be developed with reports to be published on each one. The study has started in March 2017 and is foreseen to end in 2023.

[5] SeBS Methodology: A Practical Guide for Practitioners to evaluating the Benefits derived from the Use of Earth Observation Data

1.5 Acknowledgements

Producing this case study report would have been impossible without the invaluable insights and kind assistance of key stakeholders. In particular, we wish to thank the following persons for their time spent talking with us to develop the case.

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Jason Andrews, (Merton Borough Council), Member of the *airTEXT* consortium.

Ruuta Skujina (Evenflow)

We greatly appreciate the time that case experts are able to give to us and their name listed here does not imply any endorsement of our findings.

Our time and availability to meet and discuss with experts were severely constrained by the Covid pandemic and all interviews were conducted remotely. This is a regret as the personal meetings and visits during a field visit lend a great richness to our understanding of the cases and the stories behind them. In the meantime, the story is still complete but maybe lacking in some details. We hope that you enjoy the read in any case.

This story is capturing the benefits obtained through the use of satellite data within the subject value chain. Assumptions were made throughout the value chain, based on the best of our understanding. We shall welcome expert suggestions to consolidate these assumptions, improve the used models and reduce uncertainties. Please contact authors at info@easrc.org with any question or observations.

2 Air Quality in Latvia

Clean air is vital for people - if a person can live without food for 40 days, without drinking - for 3 days, then he will not be without air for even 3 minutes. Where in a city can you get fresh air? Parks? Urban green areas and forests? Not always. The economic activity of the city and the active flow of transport on the main transport arteries on days with a slight wind and temperature inversion cause the accumulation and spread of pollution throughout the city[6].

2.1 The Quality of Our Air

Air pollution and the adverse impacts of poor air quality on our health, has become a major issue of concern in recent years. According to the WHO[7], 4.2 million people die prematurely each year[8] as a result of exposure to ambient (outdoor) polluted air (and a further 3.2m due to indoor pollution).

According to the World Health Organisation (WHO),

> "Air pollution is contamination of the indoor or outdoor environment by any chemical, physical or biological agent that modifies the natural characteristics of the atmosphere."[7]

Exacerbated by the increasing concentration of people in cities and the rapid increase in the number of motor vehicles, dangerous chemicals and particles are becoming more present in the air. Today, almost 50% of the worlds' population live in cities where ambient air conditions have been getting steadily worse as the population increases, transport networks expand, and the economic activity grows.

But air pollution is also caused by events happening outside the cities. Farming causes dust and particles from fertilisers to be thrown into the air whence the wind blows this many 10's and sometimes 100's and even 1000's of kilometers. Sand particles blown from desert regions can be transported many 1000's of kilometers as well as particles from wildfires. All these are contributing to air pollution and worsening air quality mainly in cities but also in rural areas.

Inhaled by humans, it is shown that these substances are damaging to the environment and to human health[9]. The concentration of these polluting substances varies over time and location and, whilst not entirely caused by humans, is strongly affected by human activities. Air pollution is a global problem. Figure 2-1 shows average concentration of $PM^{2.5}$ weighted by population. Whilst the greatest levels are found in a band from Northern Africa through the middle east to Asia, the levels in Europe and other developed countries is still a cause for concern as is shown by WHO

[6] Adapted from the introduction on the Riga City website.
[7] WHO web-site on Air Pollution
[8] https://www.who.int/news-room/fact-sheets/detail/ambient-(outdoor)-air-quality-and-health
[9] Health Impacts of Air Pollution, EEA

efforts to tighten guideline limits. The map is showing averages across a country which disguises the much higher levels seen in the urban areas. That this is a concern, is clear from EU efforts to introduce tighter limits[10]. We shall return to this later.

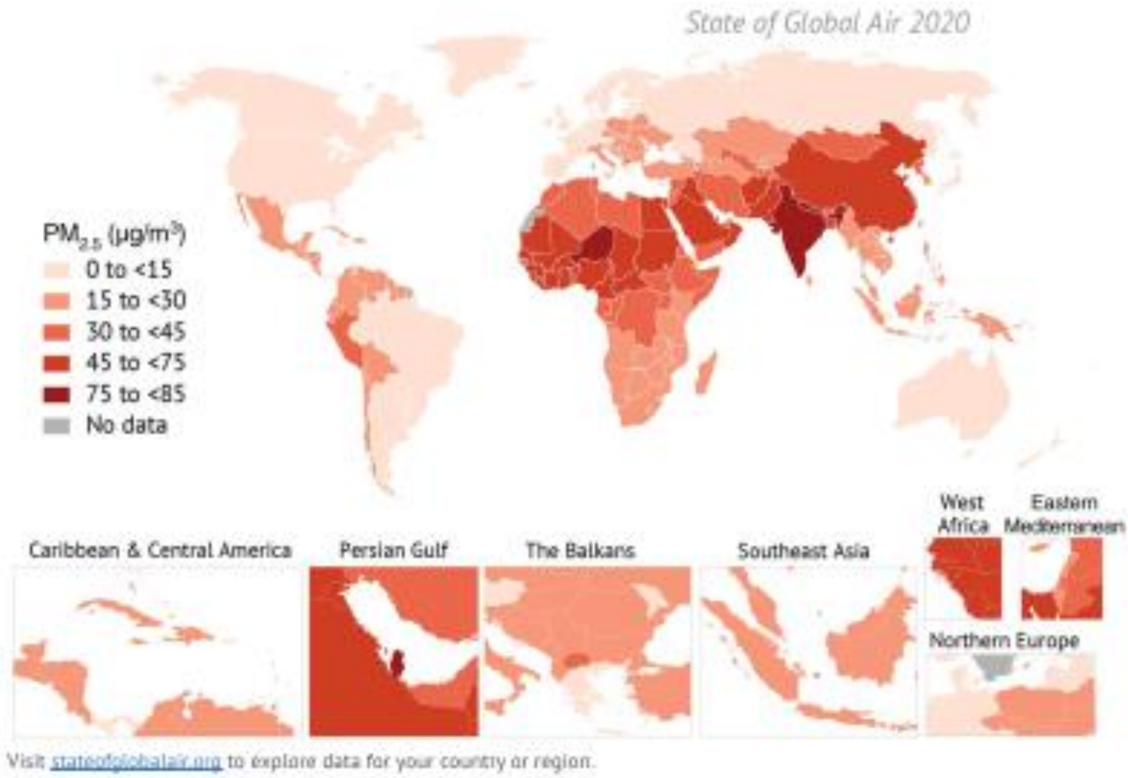

Figure 2-1: Global map of population-weighted average PM2.5 concentrations in 2019[11].

In addition to human health, air pollution threatens the environment through acidification, eutrophication, and ozone damage, causing damage to forests, ecosystems and crops, with significant impact on biodiversity. This pollution pressure can aggravate situations of nitrogen surplus via water pollution.

Three substances are the primary components of air pollution:

- Nitrogen Dioxide emissions are primarily coming from cars and other vehicles. It is a very local pollutant arising close to ground level, mostly in cities where urban transport is at its most dense. The high population density in cities leads to a high exposure.
- Ozone is formed as a result of road transport burning fossil fuels. Additionally, Ozone is formed in the upper atmosphere and hence is significantly driven by meteorological factors.
- Particles (PMI) which arise from many sources both man-made and natural (blown sand, volcanoes, wildfires). Anthropogenic sources include vehicles, home and district heating, and some industrial processes. PMI's are divided into 2 categories; fine particles PM2.5

[10] Proposal for a revision of the Ambient Air Quality Directives.
[11] State of Global Air 2020

which are less than 2.5microns in size, and PM10 which are less than 10 microns. A useful description of PMI's can be found here.

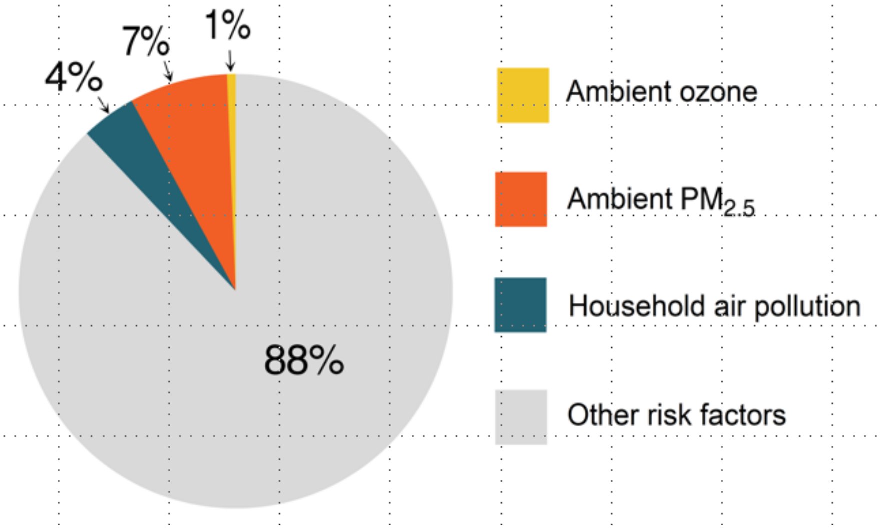

Figure 2-2: Percentage of all Global Deaths Attributed to Air Pollutants.

Of the total global deaths each year, around 12% are attributed to the various causes of air pollution as shown in Figure 2-2 - taken from the State of Global Air 2020 report[11]. From this we see that particles and especially the fine particles PM2.5, are considered to be the highest risk leading to 7% of global deaths each year. For this reason, our analysis is focused on this cause.

This is further re-enforced by the impact assessment[12] made by the EC in relation to the revised regulations on air quality[10]. This states that *the air pollutant considered to cause the greatest harm to the European population is fine particulate matter (PM2.5). This pollutant can either be a result of primary emissions (mainly from combustion of fossil fuels or biomass), or a secondary product of precursor pollutants, namely nitrogen oxides (NOx) and sulphur dioxide (SO2) (both mainly stem from fossil fuel combustion) which combine with ammonia (NH3) (which mainly stems from agriculture). Thus, concentrations of PM2.5 lend themselves as an overall headline indicator of air pollution, as significant reductions of PM2.5 can only be achieved by taking measures that reduce emissions of a range of air pollutants across a range of activities, including domestic heating and agriculture, but also transport, power generation and industry* – see Figure 2-3.

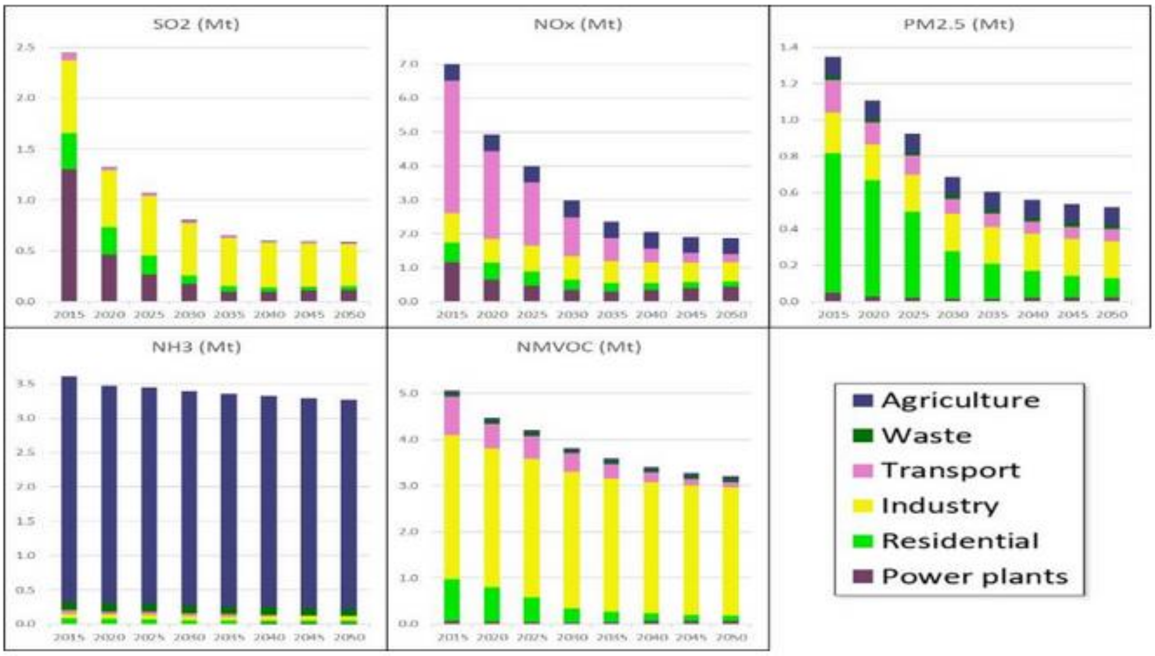

Figure 2-3: Actual and forecast levels of pollutants in the EU (baseline scenario)[12]

The world is not standing still and international action to reduce pollution has resulted in falling levels. In the EU, levels have been falling even relative to increased economic activity. Figure **2**-**4** shows the trend established since 2005. Economic growth is shown in the upper line, whilst the levels of the major air pollutants are shown below. Nitrogen Dioxide has fallen by 36% compared to the reference whilst particles have reduced by just under 30%.

Even so, the level of air pollution in the EU is considered to be too high and measures are being considered to tighten limits and reduce the risk even further[10]. In 2020, for example, fine particulate matter (PM2.5) concentrations were reported to be higher than the EU annual limit value at least at one sampling point in three EU Member States. Such concentrations above the limit value were registered in 2% of all the reporting stations and occurred primarily in urban or suburban areas.

As the limits are tightened, so interest is also growing in categorising the types of pollutant. The EC proposal introduces the possibility to start to measure these different particulates and distinguish between levels of black carbon and other ultrafine particles. So far, a lack of such data has hindered research as to what degree the different particle types cause different health problems.

Where do the pollutants come from? As indicated, the large majority are caused by urban transport which has both been increasing and becoming more concentrated in cities, exactly where the citizens are living and working. Particles are not just arising from combustion i.e. from thermic

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[12] Impact Assessment Report accompanying the Proposal for a Directive of the European Parliament and of the Council on ambient air quality and cleaner air for Europe (recast)

engines. Dust and salt thrown up from the road, brake and tyre wear also cause particles to be thrown out. Some industrial processes, such as steel production cause pollution as well as wood burning or worse coal burning stoves used for domestic or district heating. Finally, not all of the pollutants are anthropogenic, and wind born particles from wildfires or sand picked up in deserts, are a problem under certain meteorological conditions.

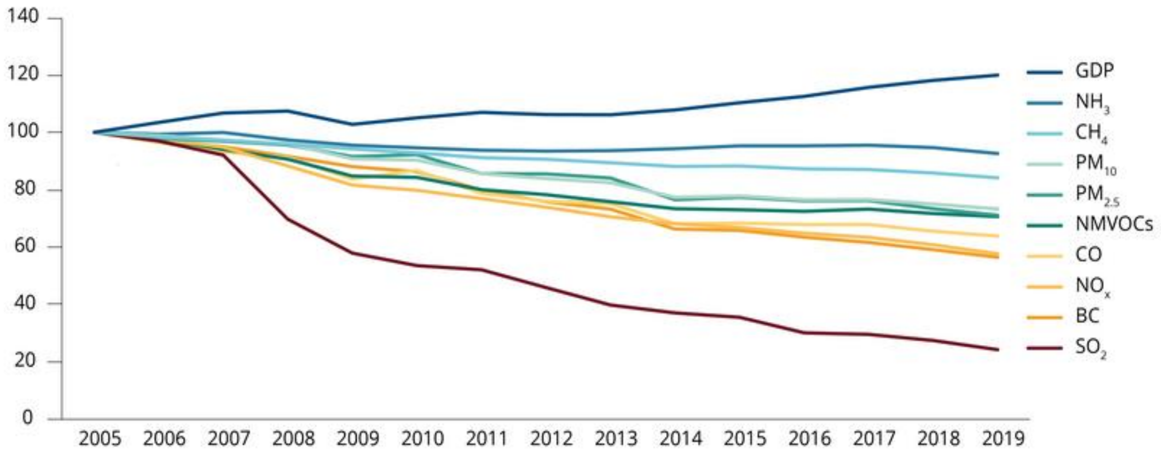

Figure 2-4: Trends in EU27 emissions 2005 - 2019[13].

All these pollutants cause difficulties and especially cardio and respiratory illnesses in humans as we shall discuss in the next chapter. Quantifying and monitoring the effects of exposure to air pollution in terms of public health is a critical component in policy discussion.

2.2 A Risk to our Health

The EEA considers that air pollution is the biggest environmental health risk in Europe.

> *"Air pollution is hard to escape, no matter where you live. It can seriously affect your health and the environment. Even though air quality in Europe has improved over recent decades, the levels of air pollutants still exceed EU standards and the most stringent World Health Organization guidelines".*

As seen in Figure 2-1, exposure to excess air pollution is a global problem. Whilst it affects all people globally, it accompanies the trend to increased urbanisation and economic growth. As a result, the impact is worse in developing countries where both these trends are more important. In recent years, both the degree of pollution and the numbers of people exposed have been rising in China and India. A discussion of this can be found on the WHO website dedicated to air pollution.

Some health effects associated with air pollution are well recognised such as increases in hospital admissions and deaths from cardiovascular diseases, respiratory diseases and lung cancer. That

[13] https://www.eea.europa.eu/publications/air-quality-in-europe-2021/sources-and-emissions-of-air

those with pre-existing cardiovascular conditions, respiratory diseases and older people are at a higher risk. But research is now showing that air pollution may be associated with a much wider range of health issues such as neurological disease, difficulties in pregnancy and diabetes.

The risk to health is driven by both gases and particles. Nitrous oxides and ozone have a neurological effect after sustained exposure. Ozone has been shown to affect the respiratory, cardiovascular and central nervous system. The offending, airborne particles are classified into two sizes. Firstly, those with a diameter of 10 micrometers (10 millionth of a metre) or less can enter deep inside a person's lungs. But the most health-damaging particles are even smaller. Those with a diameter of 2.5 micrometers or less – abbreviated as PM2.5 – can penetrate the lung barrier and enter a person's blood system. These are extremely fine particles: 2.5 micrometers is about one-thirtieth of the diameter of a human hair and, as a result of entering the blood stream, cause a wide range of health problems in addition to those caused by PM^{10} damage to the lungs and heart.

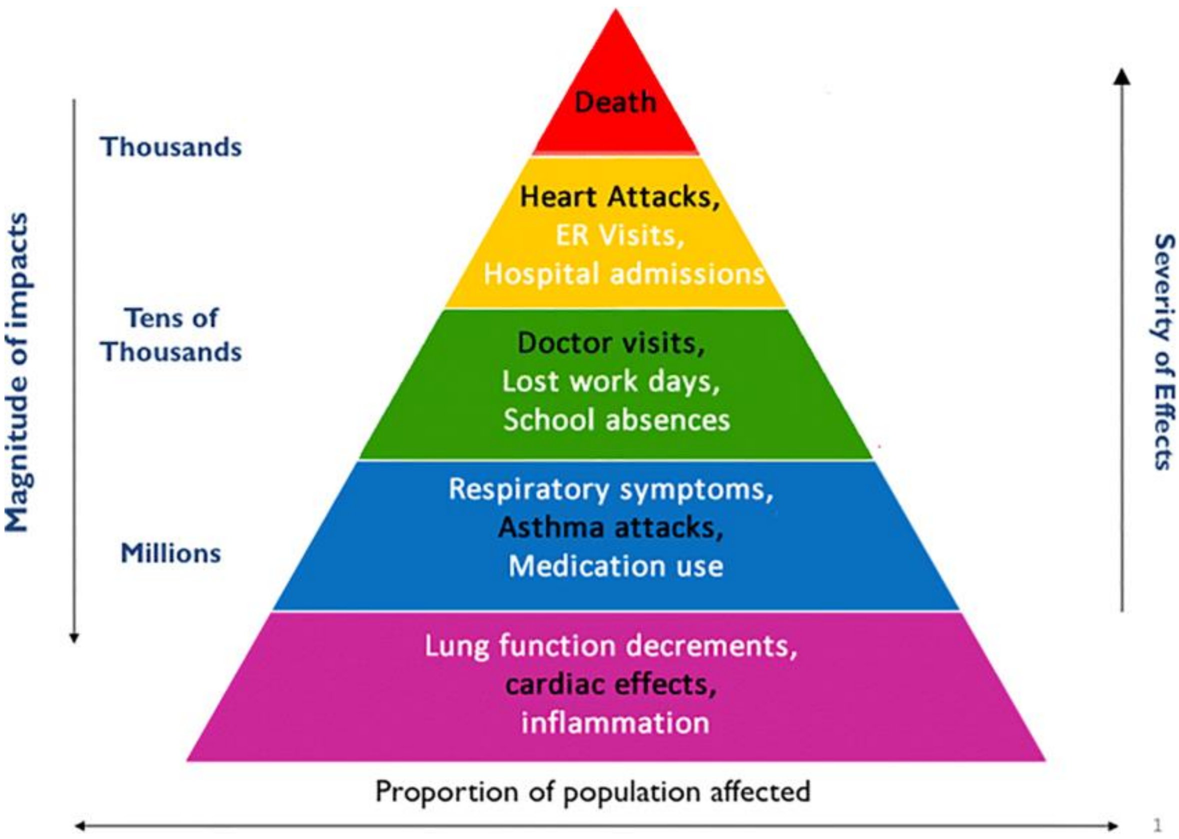

Figure 2-5: Health impacts of Air Pollution

A visualisation of the health impacts of air pollution is produced by the Benefits Mapping programme run by the US EPA[14]. Figure 2-5 shows the proportion of the population which is affected by air pollution to different degrees of severity. It is drawn from the BenMAP-CE tool which

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14 US Environmental Protection Agency Benefits Mapping Programme (BenMAP).

estimates the number and economic value of health impacts resulting from changes in air quality - specifically, ground-level ozone and fine particles.

The WHO estimates that in 2016, some 58% of outdoor air pollution-related premature deaths were due to ischaemic heart disease (inadequate blood supply) and stroke (rupture of blood vessel in the brain), while 18% of deaths were due to chronic obstructive pulmonary disease and acute lower respiratory infections respectively, and 6% of deaths were due to lung cancer.

Some deaths may be attributed to more than one risk factor at the same time. For example, both smoking and ambient air pollution affect the development of lung cancer. Some lung cancer deaths could have been averted by improving ambient air quality, or by reducing tobacco smoking. Asthma is a major cause of problems as we shall see later. Asthma is caused by particle air pollution as well as the more well-known pollen from plants and trees. Timely information on both of these can help save lives.

The results of the latest Global Burden of Disease study (GBD2019)[15] by the Institute for Health Metrics and Evaluation (IHME) has become an essential resource for policy makers in their fight against disease and to analyse the data for specific effects for instance air pollution. The reports can be found in their scientific publications (the scientific publication is usually published in The Lancet) and also on their website healthdata.org). The study is conducted every 2 to 3 years and the data provides the basis for many deeper, more focused studies including a dedicated analysis such as that on air pollution impacts was conducted using data from the 2015 study[16].

Further detailed analysis by the Health Effects Institute (HEI) along with IHME has led to "The State of Global Air" report[11] published in 2020. As shown in Figure **2**-**6**, in 2019, air pollution moved up from 5th to the 4th global leading risk factor for death, continuing to exceed other widely recognised risk factors for chronic disease like obesity (high body-mass index), high cholesterol, and malnutrition.

[15] The Global Burden of Disease: https://www.thelancet.com/gbd
[16] https://www.thelancet.com/journals/lancet/article/PIIS0140-6736(17)30505-6/fulltext

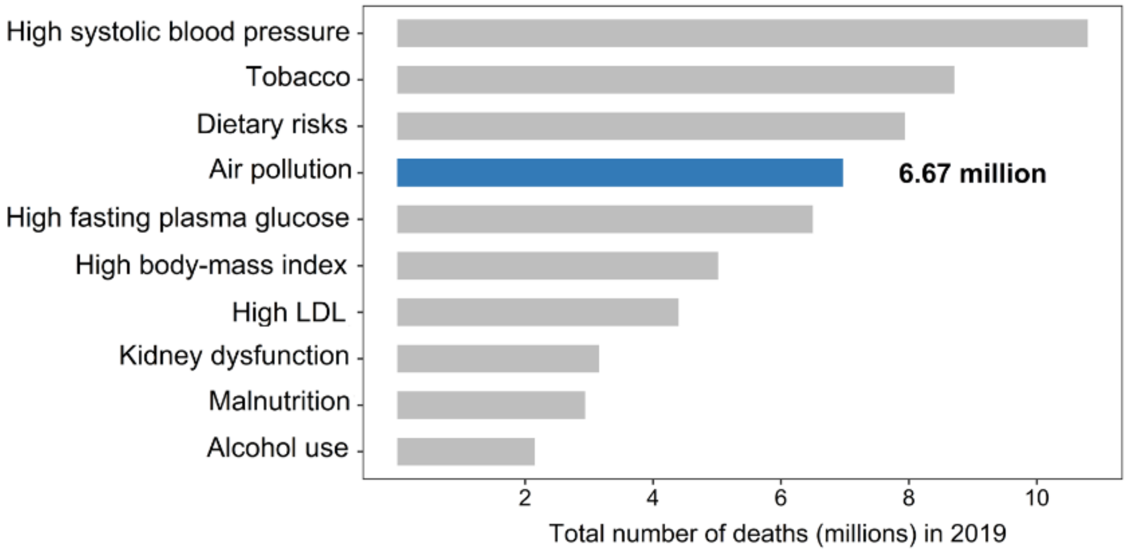

Figure 2-6: Global ranking of risk factors by total numbers of deaths in 2019[11].

In the discussion above and the analysis that follows in the report, the focus is almost exclusively on deaths caused by ambient air pollution with a focus on particles. This follows the large majority of academic studies for two reasons. First, morbidity makes up a very small share of the total health impacts of air pollution. The impact on society is dominated by the loss to society from those who die prematurely. According to a study by the World Bank and IHME, the regulatory analyses of air pollution control policies in the United States and elsewhere have consistently found that the majority of economic benefits accrued by improving air quality take the form of avoided premature deaths.

The severity of the air pollution is largely characterised by the numbers of people dying from exposure. As the pollution levels have fallen, so the death rates have as well. Figure 2-7 shows how the global death rate per 100,000 for indoor and ambient pollution has changed since 1990. The global figures are driven largely by Asian countries where it is falling due to reduced indoor pollution levels. The death rate due to ambient particle pollution has stayed fairly constant with even a slight rise.

In Europe, similar falls have been visible as shown in Figure 2-9, but in this case driven by outdoor pollution and specifically falling concentrations of particulate matter. The death rate in Europe is around 25-30 persons per 100,00 compared to a global figure of around 57.

In the EU, the EEA estimates that over 96% of the persons within the EU urban areas are exposed to air pollution which exceeds the WHO guidelines. Less than 1% are exposed to levels above the EU guidelines which are much less stringent than those of the WHO. Figure **2**-**8**, taken from the EEA annual report on air quality, illustrates this quite clearly.

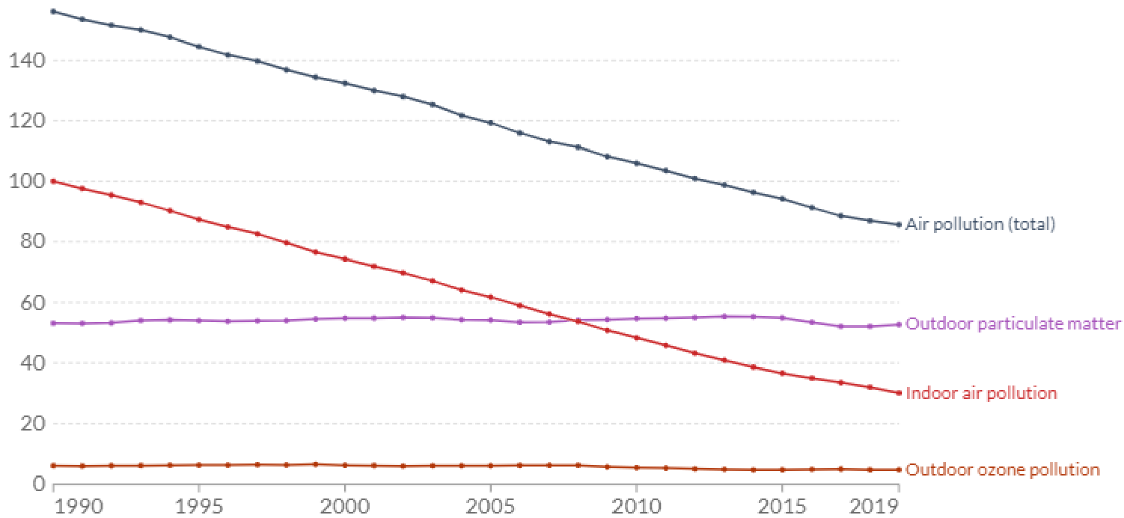

Figure 2-7: Global death rates due to air pollution per 100,000 (Our world in data)

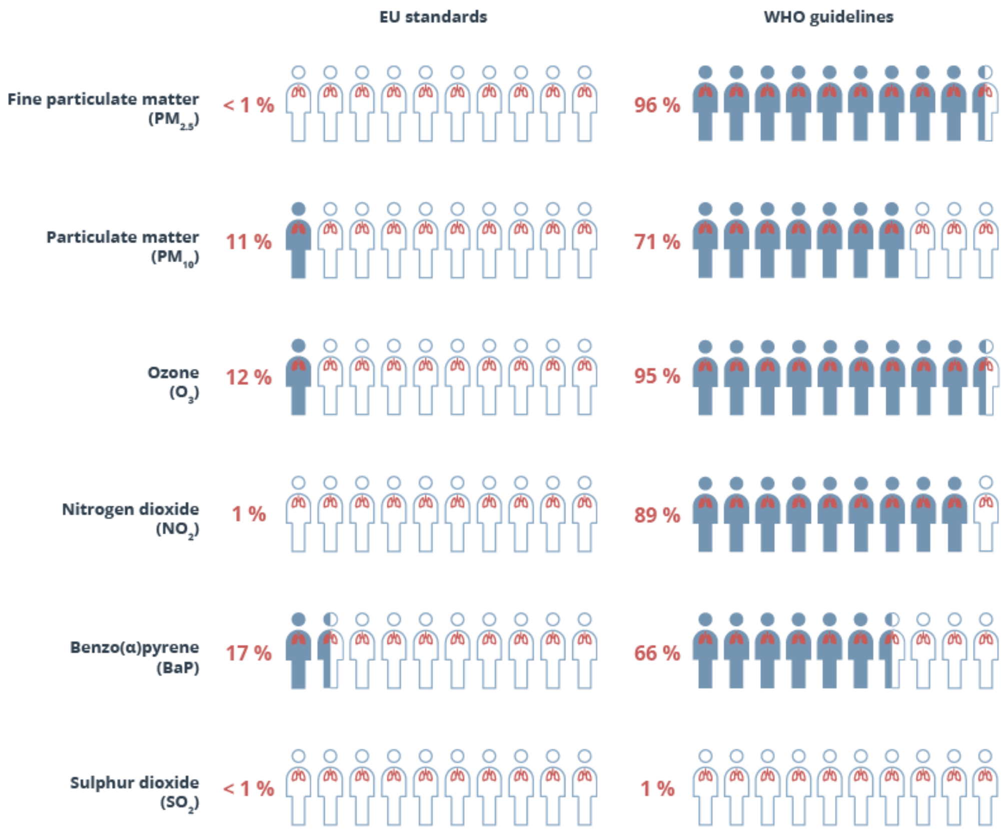

Figure 2-8: Urban populations exposed to air pollutants above the guideline limits in 2021[17].

[17] EEA Status of Air Quality in Europe in 2022

In Latvia, the death rates have also been falling significantly driven largely by the reduction in concentration of ambient particulates but also by falling indoor pollution. Today, the rates are around 30 persons per 100,000, similar to those across much of the EU.

Even if much of the focus on impacts is on deaths, many millions of people suffer from the effects of air pollution. Children and the elderly are particularly vulnerable. From the WHO fact sheet:

> *"Short term exposure to particulate matter is likely to cause acute health reactions such as irritation to the eyes, nose and throat coughing, wheezing and increased frequency of acute lower respiratory reactions.*
>
> *More prolonged and continued exposure to either high or lower levels of air pollution can also lead to an increased risk of respiratory infections, exacerbation of asthma, bronchitis or serious chronic affects including reduced lung function, ischaemic heart disease, stroke, lung cancer and premature death."*[18]

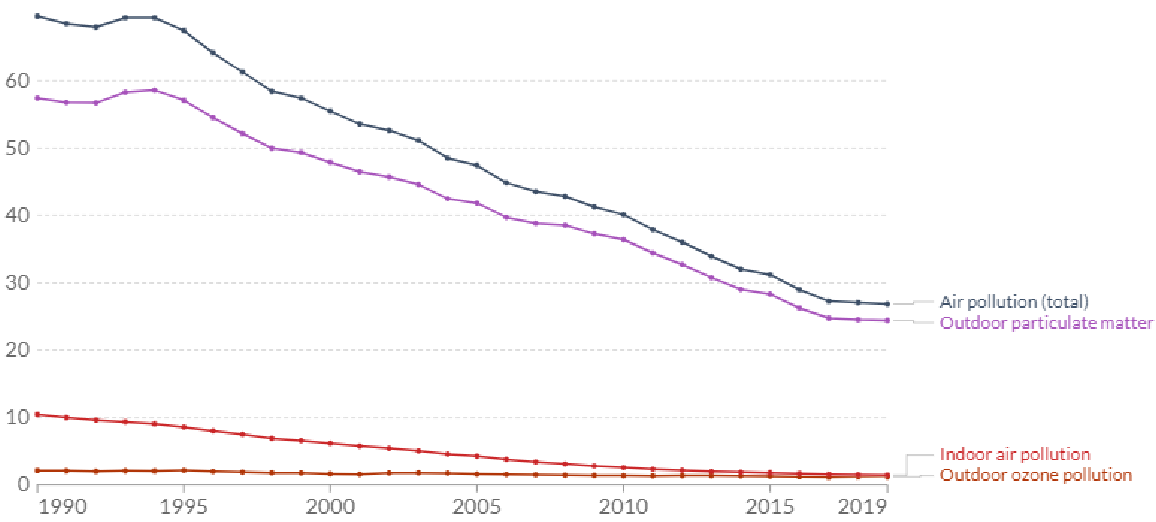

Figure 2-9: Death rates in Europe due to air pollution per 100,000 ([Our world in data](#))

The overall loss to society is generally measured by the number of DALY's (Disability-Adjusted Life-Years). The 2015 IHME study finds that in 2015, exposure to $PM_{2.5}$ caused 4·2 million deaths and 103·1 million DALY's in 2015. However, the DALY's are dominated by the years lost as a result of premature death so someone dying younger is a greater loss to society than the loss of an older person.

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[18] WHO Fact sheet 1; What is Air Pollution -2019.

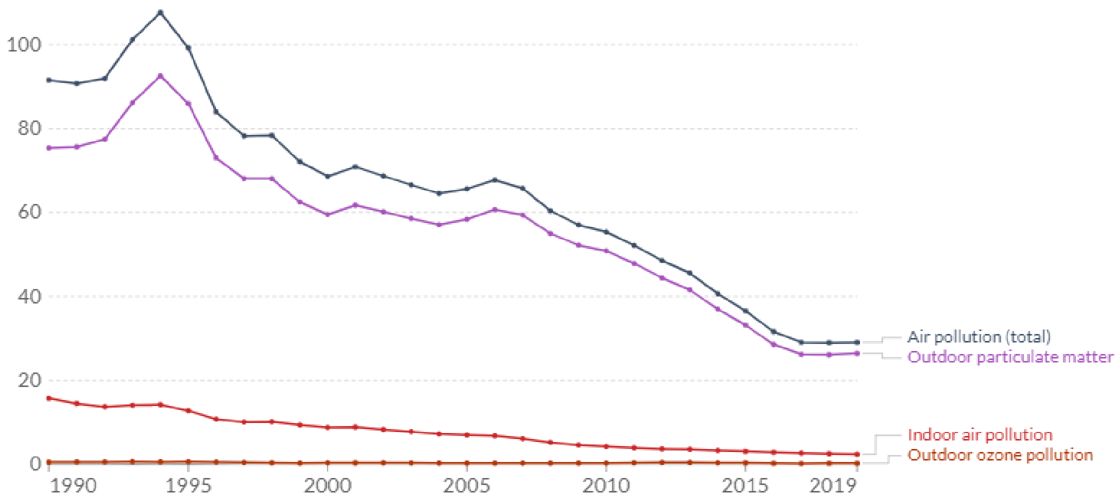

Figure 2-10: Death rates in Latvia due to air pollution per 100,000 people (Our world in data)

Whilst death rates and DALY's are a measure of the severity of impact of air pollution, the effects on human health are far more widespread. The US government National Institute of Environmental Health Sciences (NIEHS) provides an extensive summary of the health impacts for different age groups[19]. Without reproducing all the findings, children are especially vulnerable with poor air quality linked to respiratory problems in later life such as asthma, bronchitis and lung damage especially in those practicing sports in poor conditions. Some issues of brain development may be linked to breathing polluted air and also some behavioural problems. Older adults may be more susceptible to neurological disorders such as dementia, Alzheimer's and Parkinson's diseases.

To be noted also that although most focus is on cities, rural citizens are not excluded and some farm practices as well as wildfires can lead to poor air quality for extended periods of time.

So, the causes and the impacts are relatively well identified even if the links are not yet fully understood such that the problem of poor air quality is widely acknowledged. What can be done to improve the situation, and how can satellites help?

2.3 Addressing the problem at source

What can be done to combat the health impacts of ambient air pollution? Governments are introducing policies to reduce the levels of pollution whilst individuals are advised to take certain precautions. For both types of measure, information is needed to be made available to citizens and policy makers.

Reducing overall pollution levels requires a raft of different policy responses from reducing or changing the use of private vehicles, to improving public transport opportunities, to changing industrial policy in favour of less polluting processes etc. A comprehensive approach is necessary to

[19] https://www.niehs.nih.gov/health/topics/agents/air-pollution/index.cfm

make any real impact and it with this perspective that the EU is seeking to introduce the tighter limits[10].

To mitigate against the pollution which does exist, the WHO recommend that individuals take all available measures to minimize exposure to air pollution[20] as well as taking steps to avoid adding to pollution levels. People can only take avoiding action if they have timely information on the pollution levels. Information derived from sensors and models can help considerably and such information is also of immense value to those taking decisions on behalf of the community and setting policies.

The WHO currently recommends that a limit of 10ug/m3 is applied with a daily peak no higher than 3 times this. However, the goal is to reduce this to 5ug/m3 which is not today met anywhere in Europe's cities. Reducing to lower levels, especially for smaller particles which pass through our lungs, raises an interesting question of whether some pollutants are more harmful than others. At existing levels, the focus is on quantity but could this change? Is coal dust more harmful than dust from vehicle brake pads? Further research based on information which is currently not available (as recognised in the EC legislative proposals[10]) will be needed to answer this question.

The WHO is the main organisation which is providing guidelines against which these decisions are being taken. Other actors, such as UNEP, provide recommendations for measures which can be taken especially in terms of natural sources of pollution. The UNEP is currently encouraging links with digital technologies[21] to help both reduce pollution and to enable citizens to take more informed decisions to protect themselves. An example is the GEMS (Global Environmental Monitoring System for Air)[22] which, as well as providing open information on the air quality, is also enabling warning and advice to be given to concerned countries as in a recent warning given to Kyrgyz Republic.

Whilst the international actors can provide guidelines and issue warnings, actions can only be taken by the countries themselves or even at city or province level within a country. The measures are complex and quite interrelated. So, introducing a ban on coal burning stoves will have a direct impact on airborne particulates but requires investment to install alternative sources of heating. Banning diesel cars over a certain age from a city centre changes the market for these and displaces the problem to other cities as the older cars are sold on.

Yet these actions are progressive and necessary if the air quality is to be improved. Knowing that this is happening through street level measurements and open communications can be a tool to convince the local population that the policy is worthy. Increasingly, systems are being developed and introduced into the cities to make this possible.

Many European cities have now introduced portals and apps that allow their citizens to follow the evolution of the air quality, often on an hourly basis. As we shall discuss, these systems rely on both

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[20] WHO Fact sheet 2: Preventing the harmful effects of air pollution.
[21] How Digital technology and Innovation can help protect the planet.
[22] GEMS – Monitoring Air Quality

local sensors placed around the city as well as wider synoptic satellite data. Data are combined in models which provide not just a current view of the situation – which is already very useful – but also a short-term forecast. All the measurements, historic, current, and forecast enable individual and collective decisions to be taken which reduce the impact of air pollution on the population.

In this case study, we are looking at such a system which incorporates the use of data coming from the European Sentinel satellites. One of the core services provided by the Sentinel's is the Copernicus Atmosphere Monitoring Service (CAMS). CAMS provides global and European-scale forecasts twice a day on the atmosphere and, amongst other parameters, the chemicals and particles linked to poor air quality. The CAMS output is further processed and combined with local data. Examples of its use are found in London, Manchester and Riga in Latvia. Our story includes the two UK cities but is mainly focused on the impact in the city of Riga, capital of Latvia.

airTEXT is not unique and in places where localized information is not available from a city administration, global service providers can supply similar data e.g. IQAir (https://www.iqair.com/), however, at a lower spatio-temporal resolution. Nevertheless, the availability of these services indicates societal demand and great value in the supplied information that people certainly appreciate as indicated by high download numbers (e.g. in the Google Play store). It's worth noting that some of these services (e.g. PlumeLabs, https://air.plumelabs.com/) also use CAMS data (https://air.plumelabs.com/en/sources).

2.4 The Situation in Riga

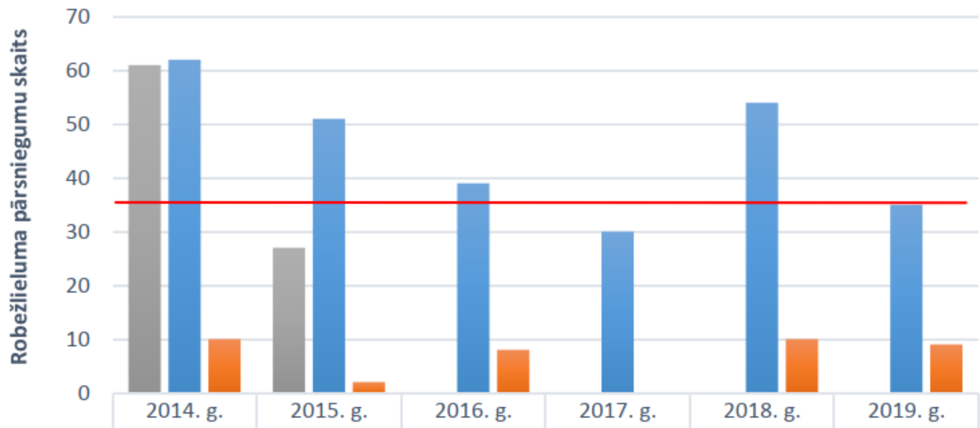
According to an EC report[23] prepared by the OECD and the WHO, population health issues in Latvia call for improvements: life expectancy remains relatively low among EU states as are health expenditures per capita, whereas avoidable mortality rates are among highest in the EU. Heart attack and stroke are much more frequent cause of death after admission to the hospital in Latvia than in other EU countries, whereas PM2.5 is shown to be a trigger and Latvia has a high rate of hospitalizations for asthma, which is more than double the EU average.

According to the WHO, there are 28,257 deaths in Latvia in 2014 of which 56.7% were due to cardiovascular disease and 2.9% due to respiratory disease. However, smoking and non-ambient pollution is a strong cause, so these numbers do not translate into a useful figure for premature deaths. In terms of premature deaths, the overall rate in Latvia is given as 30 per 100,000. The population of Latvia is 1.97m and of Riga 632,000 leading to the figure of approximately 600 premature deaths in the country and 180 in Riga.

[23] State of Health in the EU: Latvia. Country Health profile 2017.

On 22nd February 2021, Riga city council sent out a warning for residents to stay inside if possible due to the poor air quality[24]. The pollution was caused by adverse weather conditions that had created a dome of warmer air over Riga and prevented vertical mixing of the air columns. With cold air and humidity from the Gulf of Riga trapping PM2.5 and PM10 particles, combined with sand particles blown from the Sahara, the air quality was rated as “poor”. In particular, anyone with respiratory difficulties was advised not to go out for any prolonged period and to limit any sporting activities.

Such warnings do not happen often, but even so may be more than once per year. Riga is a city of 632,000 inhabitants covering an area of 300km2. Over the years, the city council has taken action against air pollution reducing it mainly to levels consistent with other European capitals. A first strategic action plan was produced 2015 to 2020 and the latest plan has been published in late 2021 covering the period 2021 to 2025.

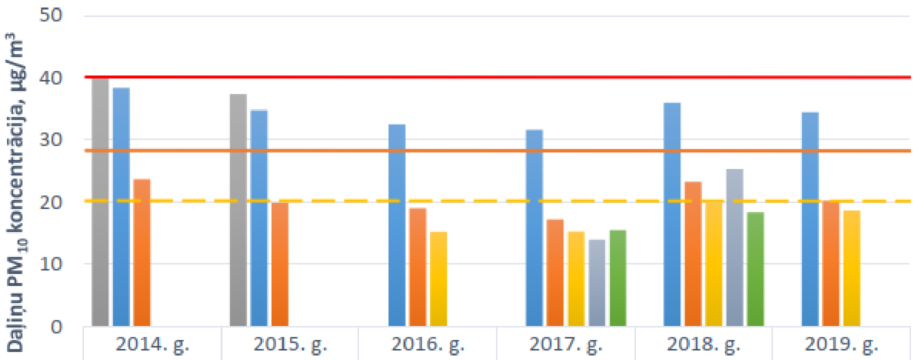


	2014. g.	2015. g.	2016. g.	2017. g.	2018. g.	2019. g.
Kr. Valdemāra iela	61	27	0	0	0	0
Brīvības iela	62	51	39	30	54	35
Kronvalda bulvāris	10	2	8	0	10	9

Figure 2-11: Number of times the EU PM_{10} limit was exceeded at 3 measuring stations.

The plan recognises that the levels of pollution in Riga exceeded the guideline limits on more days than is acceptable. Day to day measurements are made with 6 in-situ measurement stations; 3 belonging to the city and 3 to the Meteorological office. These record the actual pollution levels. Figure 2-11 shows the number of times that the limit was broken for PM^{10} at 3 of the measurement points across the city. In 2018, the limit was passed for 54 days which is 19 over the limit which was just met in 2019. Figure 2-12 shows annual average measurements for PM^{10} where the limit is regularly exceeded in at least one location.

24 Air quality in Riga is deteriorating - city dwellers are being asked to limit their physical activity outdoors



	2014. g.	2015. g.	2016. g.	2017. g.	2018. g.	2019. g.
Kr. Valdemāra iela	40.21	37.4				
Brīvības iela	38.35	34.8	32.5	31.6	35.98	34.5
Kronvalda bulvāris	23.7	19.9	19	17.23	23.27	20.25
Mīlgrāvja iela			15.2	15.24	19.86	18.63
Voleru iela				13.98	25.3	
Gāles iela				15.47	18.33	

Figure 2-12: Annual average at 6 measuring stations relative to the PM_{10} EU limit (28µg)

Whilst in the majority of cities, the air pollution is dominated by transport, individual situations do differ. in the case of Riga, it is coming from a number of different sources and varies across the districts of the city.:

- Transport. As in all cities, transport systems are creating a lot of pollution at street level particularly nitrous oxide and particles coming from cars, lorries and buses caused by engine emissions, brake dust and fine rubber particles from tyres. Riga is considering introducing a free transport pass for the days when pollution is expected to be high in order to reduce the number of cars on the roads.
- Domestic heating systems. Around 70% of homes in Riga are heated by stoves which burn wood. New builds and renovations are required to fit other forms of heating system which are less polluting and more respectful of the environment. The principal pollution are fine and coarse particles.
- The port of Riga where coal is exported and creates large amounts of dust and hence airborne particles, when it is moved. The amount of coal to be transferred is being reduced and this problem is less evident than was the case a few years ago.
- Sand and salt spread on the roads and pavements in winter, but which is liable to be lifted into the air once the ice has gone and the roads become dry.

In addition, particles coming from agriculture practice, ie the turning of the soil and distribution of fertilizers are also causing significant levels of air particles as are sand particles picked up by winds over the Sahara and blown over cities across Europe.

With regard to nitrogen oxides, the principal sources are domestic heating systems and transport. Internal combustion engines account for 80-85% of the recorded nitrogen dioxide pollution in Riga[25].

The EU legislation on air quality sets an upper limit on the allowed pollutant levels but, recognising that there are exceptional conditions, permits these levels to be exceeded for a certain number of days each year. For example, a seasonal factor which, coupled with "everyday" levels can push measurements over the limit, is the particles coming from the gritting of roads using sand and or salt. Figure 2-13 shows the number of times the limit was exceeded in the last 6 years and when this occurred on days when gritting was performed.

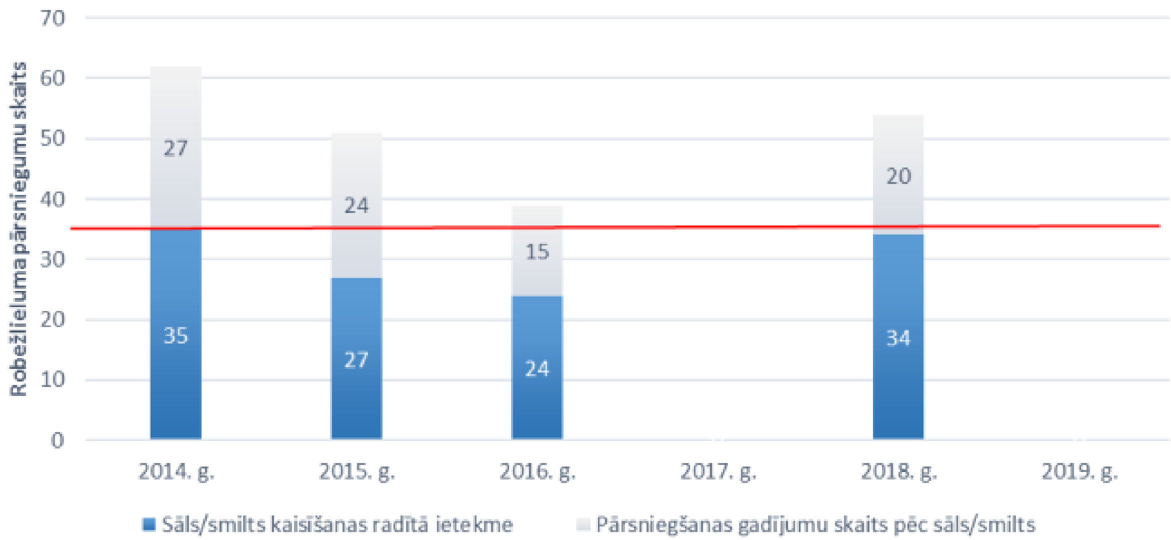


Figure 2-13: Number of times that the EU limit was exceeded when salt was applied (light grey) and when it was not applied (blue).

These data are fine for knowing the historical levels of air pollution which can help set the city policies. In order for vulnerable citizens to react, forecasts are required. This is made possible by the service Riga *airTEXT* which uses data coming from the Copernicus Atmosphere Monitoring Service (CAMS) together with detailed modelling of local sources to establish a forecast of up to 3 days ahead. The dominant sources of air pollutants across Riga in 2019 are shown in Figure 2-14 and in Figure 2-15.

[25] Air Quality in Riga and its Improvement Options; Janis Kleperis et al, Riga Technical University.

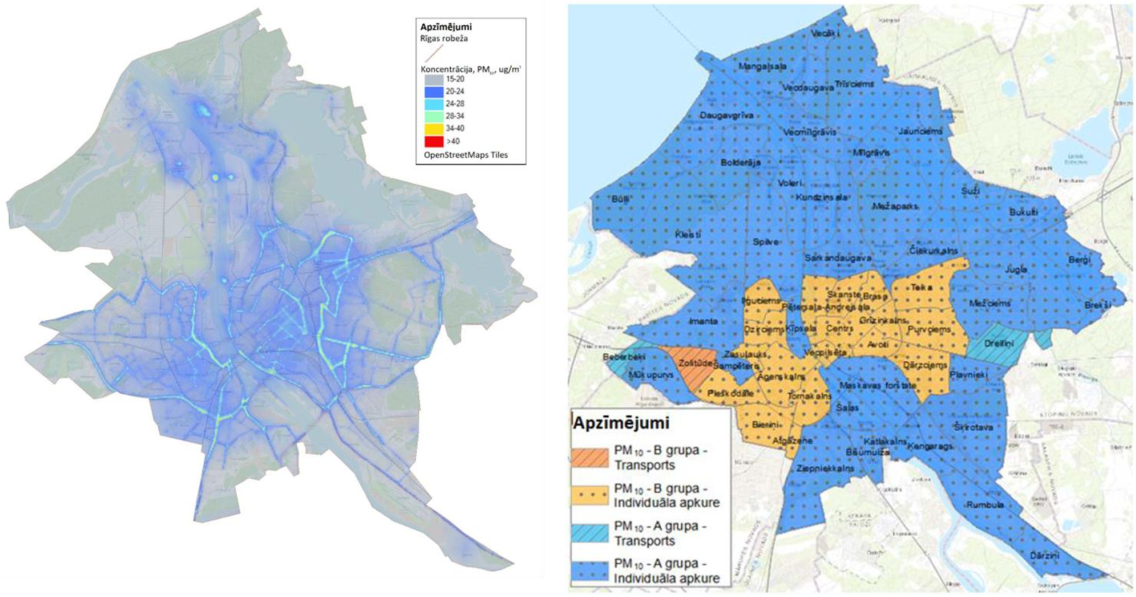


Figure 2-14: The average concentrations of PM10 pollution in the different Riga districts (left) and their primary sources (right).

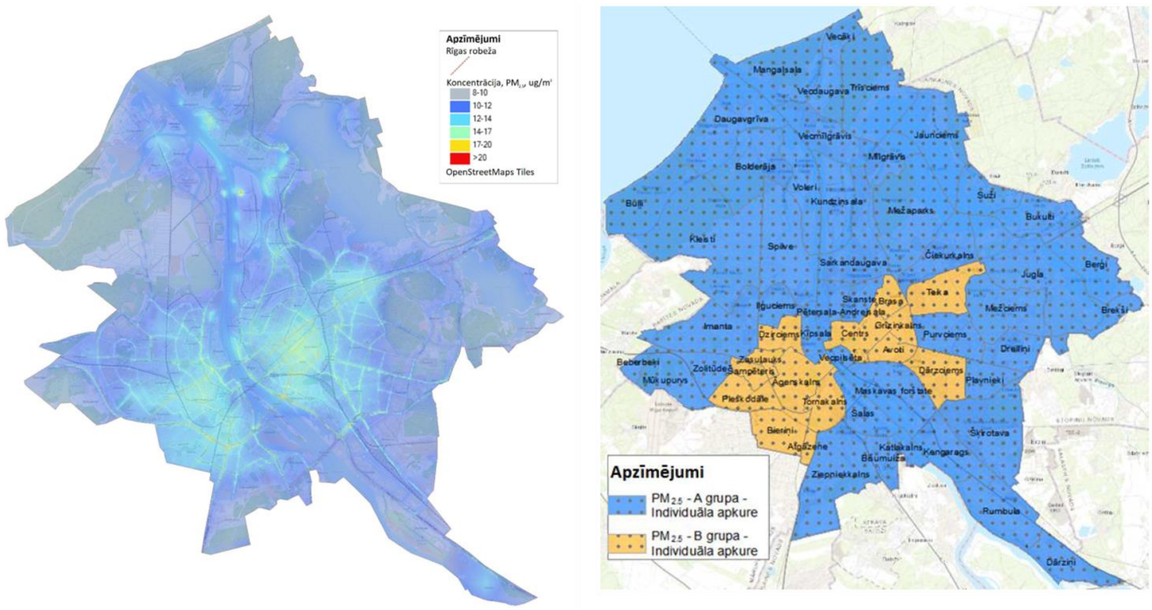


Figure 2-15: The average concentrations of PM2.5 pollution in the different Riga districts (left) and their primary sources (right).

The sources identified are transportation and domestic heating ("apkure"). The knowledge of the cause drives the principal policy measures to be taken in each district.

The above figures show the average levels of particle air pollution. In Figure **2-16** is shown how this varies over time with a 2-year window. The lowering of pollution levels as a result of restricted activity during the Covid19 crisis is visible between March and September 2020. A number of peaks of greater than 20ug/m3 which is the health limit are visible.

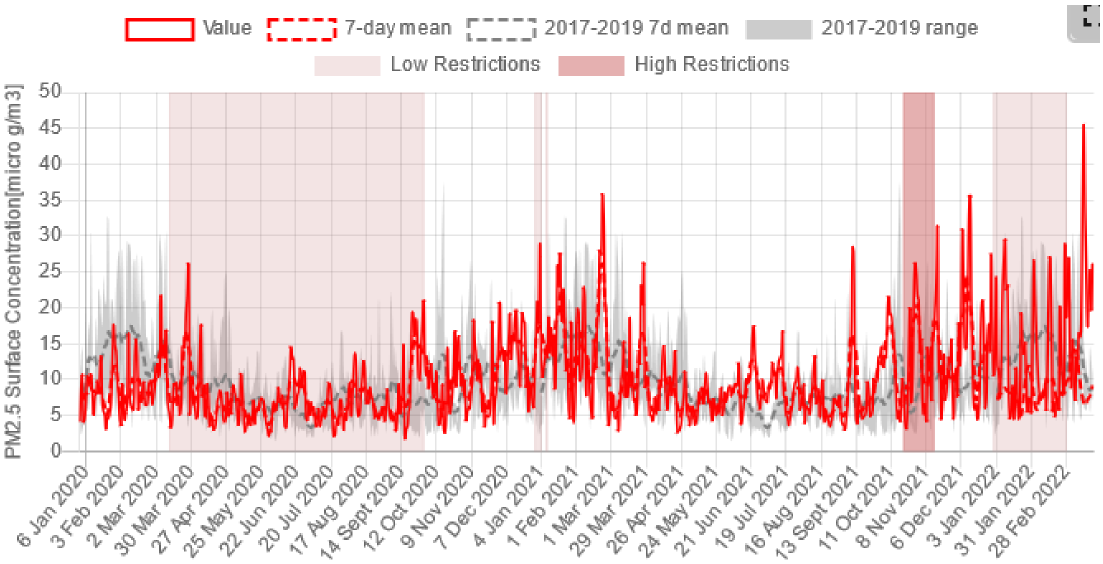


Figure 2-16: CAMS PM2.5 daily mean over RIGA

2.5 Mitigation by Information on Ambient Air Quality

Historical data of the levels of pollution and where they occur are vital to help policy makers determine measures through legislation to reduce them. Solutions are now emerging which will not only measure the air quality but also provide forecasts of when it may become particularly bad. The use of mobile technology allows people, and especially those most vulnerable, to receive warnings when poor air is forecast and advising them to adapt their behaviour and/or avoid the worst affected parts of the city.

Such a service has been introduced in Riga in 2018. In February of that year, the Riga city council launched the Riga *airTEXT* service which had been under trial over the previous 4 months. Initially, this was provided with the support of the ECMWF and, since the end of 2019, the provision of the service is financed by Riga City council and the technical implementation is made by ELLE (Estonian, Latvian, Lithuanian Environment), a company in Latvia providing environmental consultancy, together with the Cambridge Environmental Research Consultants (CERC) in the UK.

Data for the service is coming from CAMS and city models produced by ELLE using the ADMS-urban software from CERC. Local meteorological forecast data for the city and surrounding region is introduced and forecasts of air quality, for 6 districts in the city of Riga, for the next 3 days are generated. A few measurements coming from fixed points in the city are used to cross-check and validate the forecasts.

One of the key aspects that often emerges during our analysis of cases concerns the role that the service plays in supporting the design of the regulatory environment. For the use of Riga *airTEXT* this is not the case.

The data necessary to design and implement legislation on air quality comes from in-situ monitoring of the air; either permanent stations or temporary sensors situated at strategic points. The primary purpose of the Riga *airTEXT* service is to predict when the air quality will become poor and hence empower citizens to take better decisions on when to go out and where they should not go.

As we shall see later, Riga *airTEXT* is based upon a product called *airTEXT* which was developed and introduced into London some years earlier. For this reason, reference is also made to London and the service which is offered there.

2.6 Informed Decision Making

> *"As many European cities are growing rapidly in size and population, and more people are potentially exposed to air pollution, it becomes increasingly necessary for local authorities to follow coordinated and integrated policy strategies to achieve better air quality in cities[26]."*

2.6.1 What Decisions?

Information on the quality of the air can lead to 3 types of decision requiring 3 different types of information:

- Policy decisions are based on historic information. These can be to introduce traffic free areas, measures to reduce motor vehicles, changes to building or industrial practices or even to collect data where more data is needed.
- Operational decisions, which use current and forecast information such as the introduction of temporary traffic restrictions or if/when implemented the use of "dust tickets" for the Riga public transport system.
- Social decisions to enable individuals who are vulnerable to air pollution, to take daily decisions on their activities.

CAMS together with local, in-situ sensors and population information can serve the first need directly but the resolution is generally not sufficient. The ADMS-urban model transforms the coarse resolution into much more localised data and hence is much more used by the Riga City Council to support the development of the Air Quality Management Plan. The same process drives the Riga *airTEXT* service which then supports the operational and "social" decision making.

[26] EEA Report 24/2018. Europe's urban air quality — re-assessing implementation challenges in cities

2.6.2 What data?

The key data being used relate to the quality of the air in particular districts in the city. Improving understanding is a key prerequisite for implementing the appropriate policies for improving air quality. It is acknowledged (for instance in the conclusions to the WB / IHME report[16]) that satellite data is essential to measure air pollution. However, ground measurements are equally necessary to add precision and importantly to calibrate the measurements made by satellites.

The results from CAMS are European-scale and provide useful insights for decision makers when developing a regional picture. The data becomes more useful when combined with local urban models (as is the case with *airTEXT*) which helps understand in better detail where the sources are having an impact.

The result is accurate air quality measures at a street-level scale and at daily or even more frequent time intervals.

In the future, better data on the links between the air quality, the type of pollution and health is needed. Possibilities to collect this data are being explored as will be discussed in chapter 3.4.

2.6.3 What alternatives?

For historical and near current data, in-situ sensors can be used to gather the density of pollutants in particular locations. This is rather expensive and is limited in the points which can be monitored. Otherwise, the use of the atmospheric models is necessary to understand what is happening on a broader scale.

Models also have limitations and if the conditions change. For instance, if a pandemic breaks out or a conflict situation, the forecasts will not necessarily reflect the reality. In this case, the use of satellites which can operate on a sustained and non-intrusive basis may be the only means to collect new data. New sensors can help by proving new and better data sources (see Chapter 3.4).

An interesting example of this, was seen in 2020 when the Covid-19 pandemic broke out. Figure 2-17, taken from the RACE[27] website set up in 2020 by ESA and the European Commission, shows this effect for Southern Europe. The first figure shows the average NO2 concentrations across southern Europe during the period March/April 2019. Increased densities are immediately visible over the major cities and developed areas. The lower figure is a comparison showing the same area 12 months later as most of Europe was locked down during the first wave of Covid19 infections. A strong reduction in particles and polluting chemicals has been observed during periods of confinement which has rapidly reversed as the various measures end and economic activity rebounds.

According to the EEA, "*in 2020, concentrations of nitrogen dioxide (NO_2) temporarily fell as a direct result of reductions in road transport during COVID-19 lockdowns. Reductions in NO_2 annual mean*

[27] RACE = Rapid Action on Coronovirus and EO.

concentrations of up to 25% were seen in major cities in France, Italy and Spain; during the first lockdown in April 2020, NO_2 concentrations monitored at traffic stations fell by up to 70%."

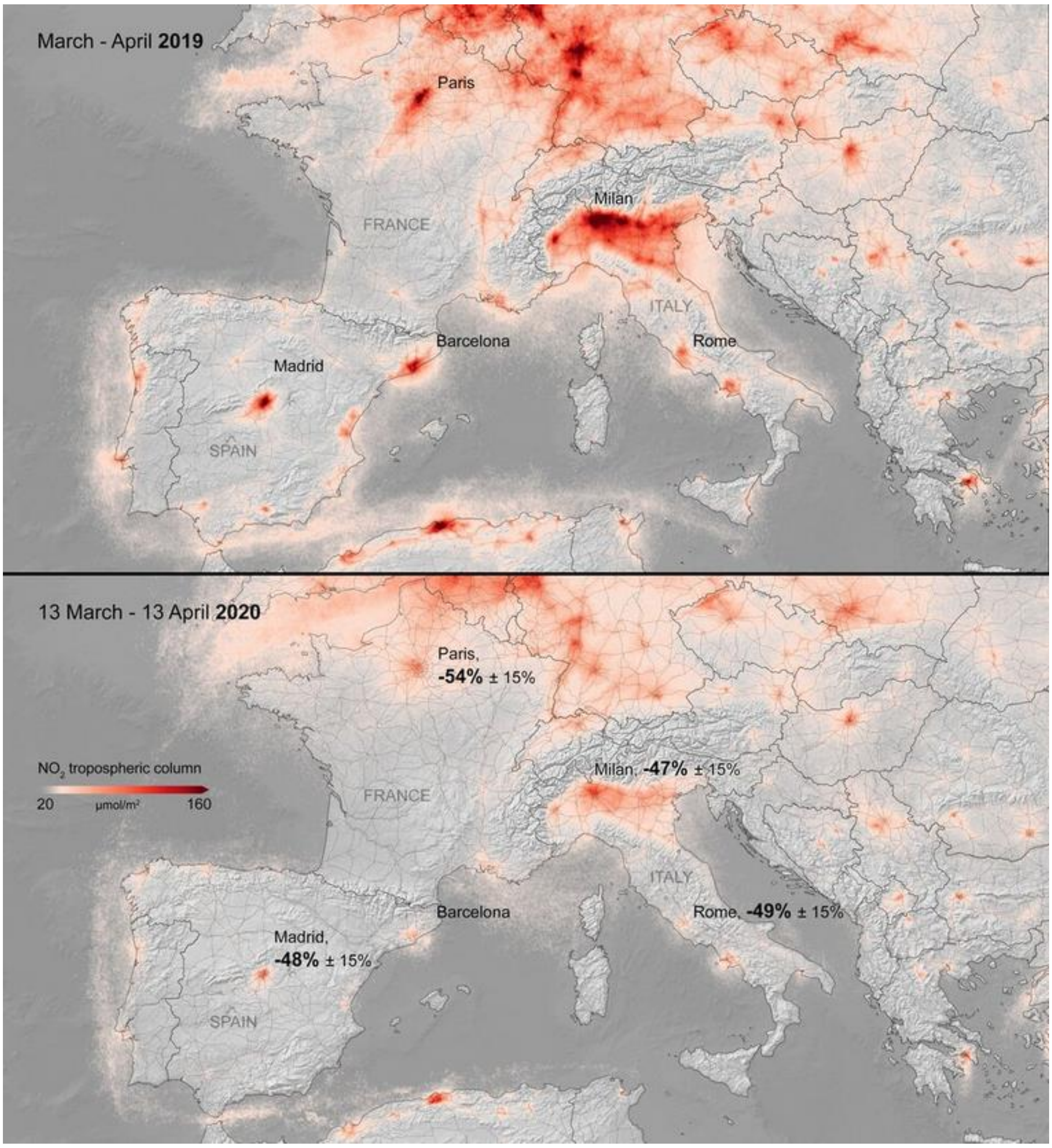


Figure 2-17: NOX concentrations over Europe March-April 2019 and 2020.

The Covid pandemic was an exceptional situation where the impact on social behaviour and hence emissions led to a large effect. Smaller impacts are harder to see, for example a transport strike or extreme weather conditions also lead to changes but not always visible. Improving the accuracy of the air quality information and knowledge of how social patterns impact on this will become more and more possible as resources are deployed.

3 The Use of Sentinel Data

3.1 How can Satellites help to monitor Air Quality?

The evolution of the science of atmosphere monitoring has developed dramatically over the last 50 years as a result of more and better sensors being carried on satellites and other platforms as well as computing and communications technologies. As a result, our understanding of atmospheric dynamics and the ability to forecast the weather has reached the point where useful information can be made available outside the science community to policy makers and citizens alike.

Historically, this is the core mandate of the ECMWF (European Centre for Medium-range Weather Forecasting). But is only recently, with the inception of the Copernicus programme, that monitoring the atmospheric composition has received a strong boost through the focus as one of the 6 core services of Copernicus: the Copernicus Atmosphere Monitoring Service (CAMS). CAMS makes use of the global Integrated forecasting System (IFS) which lies at the heart of ECMWF operations and is in effect their core competence.

Before entering into the specifics of this case and the air quality monitoring services implemented in Riga, it is important to understand how global monitoring systems help to inform the local air quality systems and also how satellite data is used in such models. These bring together the many data sources used in meteorological modelling with additional data, also from satellites and other sources, which inform on the atmospheric composition. Satellites can provide accurate estimates of different variables that are relevant for air quality.

Weather forecasting is fundamental for estimating air quality because it helps to estimate the possible transport of air masses, particles and pollutants sometimes far away from their emission points. However, to get reliable estimates at street level, this information must be integrated with lots of data from in-situ monitoring stations and merged with existing knowledge of the underlying physics.

It is fair to say that, as for weather forecasting, providing reliable air quality forecasts for any time horizon would be impossible without the global data that satellites can provide. However, at the moment, they cannot provide direct estimates of all the individual pollutants at high spatial resolutions that often require in-situ measurements and complex numerical modelling. The impact of and single data source within any such system is therefore not easily recognizable. With the focus of SeBS being to study the impact of Sentinels data, one of the key issues we faced when considering this case was therefore the dilution of the impact of Sentinel data on the final *airTEXT* service. In fact, *airTEXT* t is not using Sentinel data directly but is using the outputs of the CAMS which in turn is using, among others, data from Sentinel 3 and Sentinel 5P as well as from many other satellites forming a part of the global observing system. Consequently, the attribution of the benefits being due to Sentinel data is hard to analyse. To understand the service and the contribution that Sentinels make, we need to look at CAMS as well as *airTEXT*.

airTEXT was initially developed in London and much of the operating experience has come from research based in London conditions. As a result, we cannot avoid describing *airTEXT* in relation to its implementation in London whilst making links where possible to the situation in Riga. Hence, although the case is presented and analysed from the perspective of Riga *airTEXT*, many considerations are coming from developments in the UK.

3.2 Copernicus and the Sentinels helping to monitor air quality

Copernicus is an EU flagship programme[28] with the goal of meeting European geo-information needs. At its heart is the most complete, operational satellite system in the world; owned by the EU and operated by ESA and Eumetsat and currently comprising six types of satellites, see Figure 3-1.

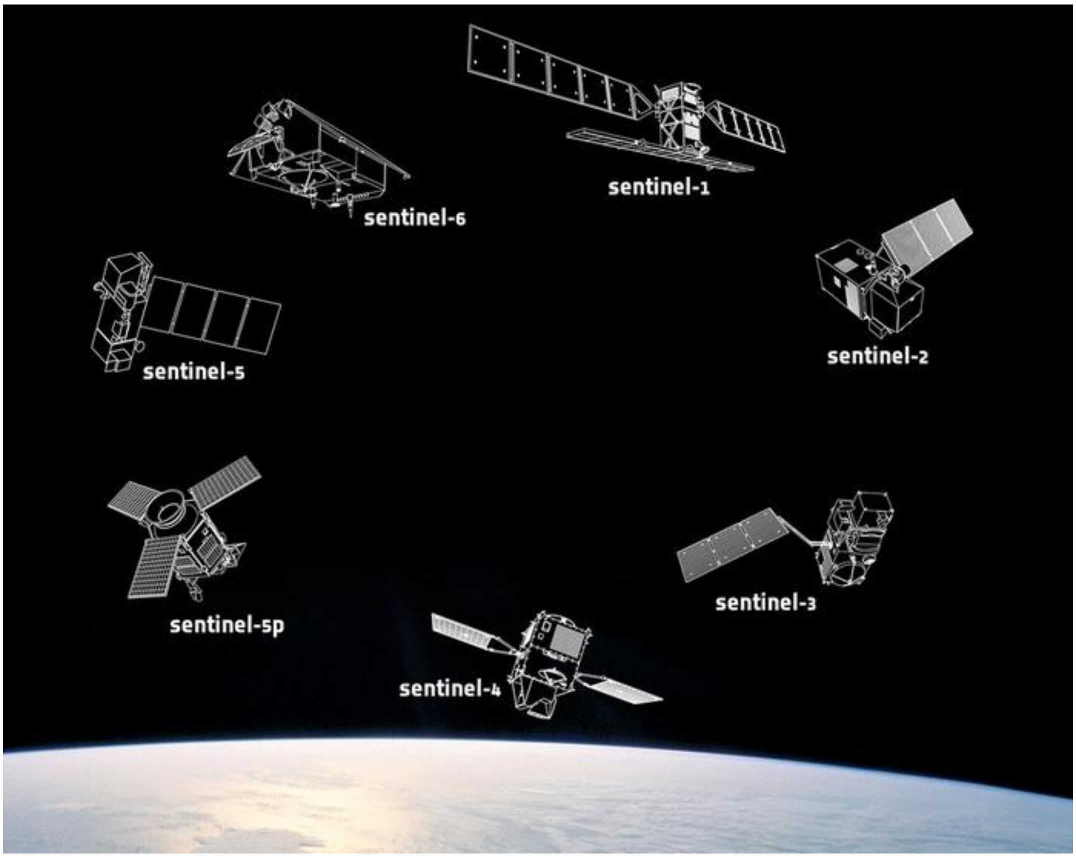


Figure 3-1: Current Sentinel satellites

As well as the satellites, Copernicus operates 6 "core" services which are designed to meet public information needs. These 6 services are shown in Figure 3-2. One of these, the Copernicus Atmosphere Monitoring Service (CAMS), lies at the heart of *airTEXT*. The CAMS is operated by the ECMWF using data from more than 40 satellites as well as thousands of ground-based observation stations, aircraft, ships and balloons. CAMS combines information from these observations with computer models of the atmosphere to generate an accurate estimate of atmospheric variables

[28] https://www.copernicus.eu/en

such as temperature, ozone concentrations and amount of aerosol particles. Using these estimates as a starting point, the models can then produce forecasts for the coming days[29].

Figure 3-2: Copernicus "Core" Services

Amongst the 40 satellites, CAMS is using data coming from Sentinel 3 and from Sentinel 5p. The more important is perhaps Sentinel-5P, from which CAMS is actively assimilating observations of the pollutants ozone, nitrogen dioxide and sulphur dioxide. CAMS is also investigating including data from the Sentinel-3 satellite into its tool for monitoring wildfires – the Global Fire Assimilation System (GFAS). GFAS uses satellite observations to produce daily estimates of the emissions of pollutants from fires. It is fair to say that, as is the case for weather forecasting, providing reliable air quality forecasts for any time horizon would be impossible without the global data that satellites can provide.

[29] About CAMS – Observations.

The satellite data

Sentinel-3 carries a suite of cutting-edge instruments such as a medium-resolution multi-spectral imager, a thermal infrared scanner and a topography payload. The mission is based on two identical satellites orbiting in constellation for optimum global coverage and data delivery. For example, with a swath width of 1270 km, the ocean and land colour instrument will provide global coverage every two days.

Sentinel-3 is Copernicus workhorse for monitoring and understanding large-scale global dynamics, with systematic measurements of the Earth's oceans, land, ice and atmosphere. Over oceans, it provides essential information in near-real time to support ocean and weather forecasting, ocean topography, marine pollution and biological productivity. Over land, it supports monitoring wildfires, mapping land use and vegetation health, as well as the water level and quality of rivers and lakes.

Copernicus Sentinels data are available under an open and free data policy.

Sentinel-3 data can be accessed at: https://scihub.copernicus.eu

More info: https://sentinels.copernicus.eu

The satellite data

The **Copernicus Sentinel-5 Precursor** mission is the first Copernicus mission dedicated to monitoring our atmosphere. A precursor to the future Sentinel-5 mission, it has the main objective to perform atmospheric measurements with high spatio-temporal resolution, to be used for air quality, ozone & UV radiation, and climate monitoring & forecasting.

Sentinel-5P carries onboard the TROPOspheric Monitoring Instrument (TROPOMI), a state-of-the-art spectrometer that maps the global atmosphere with a spatial resolution as high as 5.5 km by 3.5 km and a swath of 2600 km. It provides estimations of aerosols as well as of a multitutde of trace gases such as O3, NO_2, CO, CH_4 and formaldehyde, which affect the air we breathe and therefore our health.

Copernicus Sentinels data are available under an open and free data policy.

Sentinel-5P data can be accessed at: https://scihub.copernicus.eu

More info: https://sentinels.copernicus.eu

3.3 The Service – Riga *airTEXT*

Riga *airTEXT* is based upon the *airTEXT* service which is in turn based upon outputs generated by the CAMS. To get the full picture, we need to look at each of these in turn.

3.3.1 The Copernicus Atmospheric Monitoring Service (CAMS)

CAMS combines observations with a numerical model of weather and atmospheric composition to create detailed analyses and forecasts of atmospheric composition. Observations are coming from several different platforms and the results of running the models are presented in easily assimilated forms, see Figure 3-3.

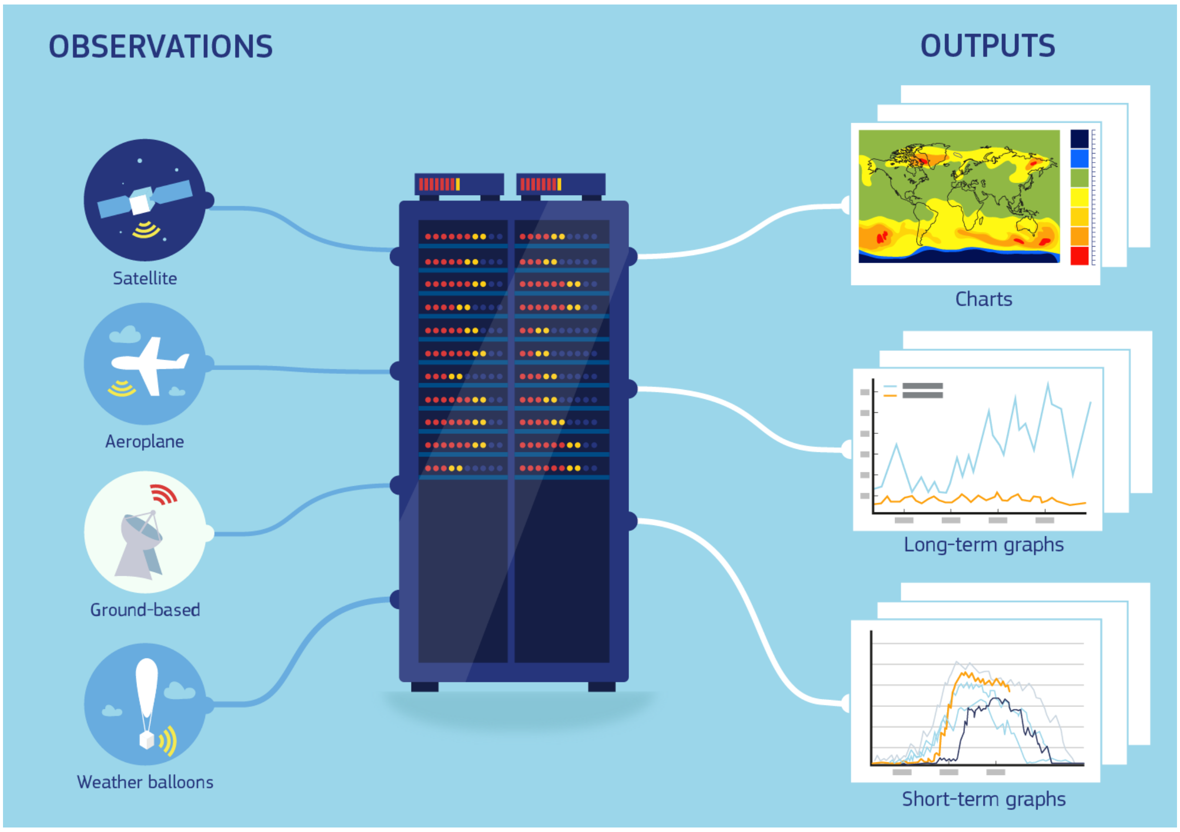


Figure 3-3: Representation of the CAMS (credit: ECMWF).

A global production system is used to produce the daily forecasts of pollutants, aerosols and greenhouse gases across the globe. Satellite observations of atmospheric composition are merged with a detailed computer simulation of the atmosphere using a method called data assimilation. The resulting analyses, i.e. maps of atmospheric composition, are used as initial conditions for the daily forecasts of atmospheric composition.

A regional production system is used to generate forecasts across Europe. Several (seven) different models are used to improve the accuracy of the output. Results are compared over years to adjust the models to find the most accurate forecast. This enables the forecasts to become more accurate for the time period of interest. In other words, the air quality up to 3 days ahead is forecast with good confidence. The regional production system also improves the spatial accuracy of the measurements which are used for forecasting, allowing more precise information to be available on the ground.

Supplementary production systems then produce the outputs tailored to the specific products. For a more complete explanation of CAMS, as well as the Copernicus Climate Change service (C3S) operated by ECMWF, see Air Quality, Climate Change and Public Health.

ECMWF work with other organisations to produce outputs which can be used in specific services. An example of this is *airTEXT* but many other third-party providers are using the outputs to develop their own tailored services.

3.3.2 The *airTEXT* Service

*air*TEXT is a service providing air quality 3-day forecasts of air quality, pollen, UV and temperature across Greater London. It provides this information as well as alerts by SMS text message, email and voicemail to the general public across greater London. *air*TEXT is an independent service, operated by Cambridge Environmental Research Consultants (CERC) Ltd in partnership with a Consortium made up of representatives from all the member local authorities, the GLA, Public Health England and the Environment Agency.

*air*TEXT was launched in London in 2007 as a partnership between the newly created *air*TEXT consortium and CERC. Other stakeholders include ESA which funded the initial project called PROMOTE in 2003 under the preparatory activities for GMES (the forerunner of Copernicus), and the European Commission which funded several research activities (including the FP7 PASODOBLE project) from which the service evolved.

The London Olympics in 2012 motivated further significant developments in the *air*TEXT product which made the service available on mobile phones. The service was continued supported by various grants and small contracts until, in 2017 a major milestone was reached when enough of the London boroughs agreed to pay an annual subscription mostly covering the service operational costs.

The air quality forecasts are produced using information from weather forecasts and forecasts of pollution across Europe from the CAMS together with very detailed data on many thousands of pollution sources across London are fed into the ADMS-Urban air quality model developed by CERC to model air pollution dispersion at a high degree of spatial resolution (7m). These forecasts are issued twice a day at about 7am and 7pm. The forecasts are updated throughout the day using real-time monitoring data from in-situ monitoring stations.

3.3.3 Riga *airTEXT*

The Riga *airTEXT* service is a street-scale, local level air quality forecasting service for the Latvian capital Riga. It has been developed by ELLE and CERC with partners Riga City Council and the Latvian Ministry of Environment. The development was funded by CAMS/ECMWF as a promotion of the CAMS service.

The RIGA *airTEXT* service uses the CAMS regional ensemble air quality forecast as boundary conditions for street-scale, local air pollution modelling and uses CAMS forecasts of UV index and pollen to provide 3-day air pollution, pollen, UV and temperature forecasts for the general public of Riga. The operational service includes:

- A dedicated Riga *airTEXT* website in English and in Latvian,

- High-resolution maps of overall air quality, NOX, PM10, PM2.5 and ozone for the region enclosed by the Riga city boundary, expressed using a colour-coded Air Quality Index (AQI) system,
- Air quality alerts for 7 Riga districts separately, which are sent directly to subscribers at no cost to them by SMS and email,
- A smartphone app with colour-coded, zone specific forecasts of air pollution, UV pollen and temperature range; these forecasts are available as an API for integration into 3rd party apps.

Riga *airTEXT* was launched in February 2018 after the 2-year development activity. The service is based on that used in London with an urban model for Riga mapping the sources of pollution and air quality forecasts coming from CAMS. Dataflow within the processing chain is shown in Figure 3-4.

A cutting-edge computer system at CERC automatically combines state-of-the-art satellite observations, European air quality forecasts from CAMS and ultra-high-resolution air quality data for Riga using the world-leading system ADMS-Urban, as shown in Figure 3-6. ADMS-Urban simulates pollution dispersion and chemical reactions in large urban areas, accounting for thousands of individual sources and the complex air flow shaped by buildings and streets. Traffic flows, street canyons, open green spaces, factories are amongst the many features which are built into the ADMS-Urban model.

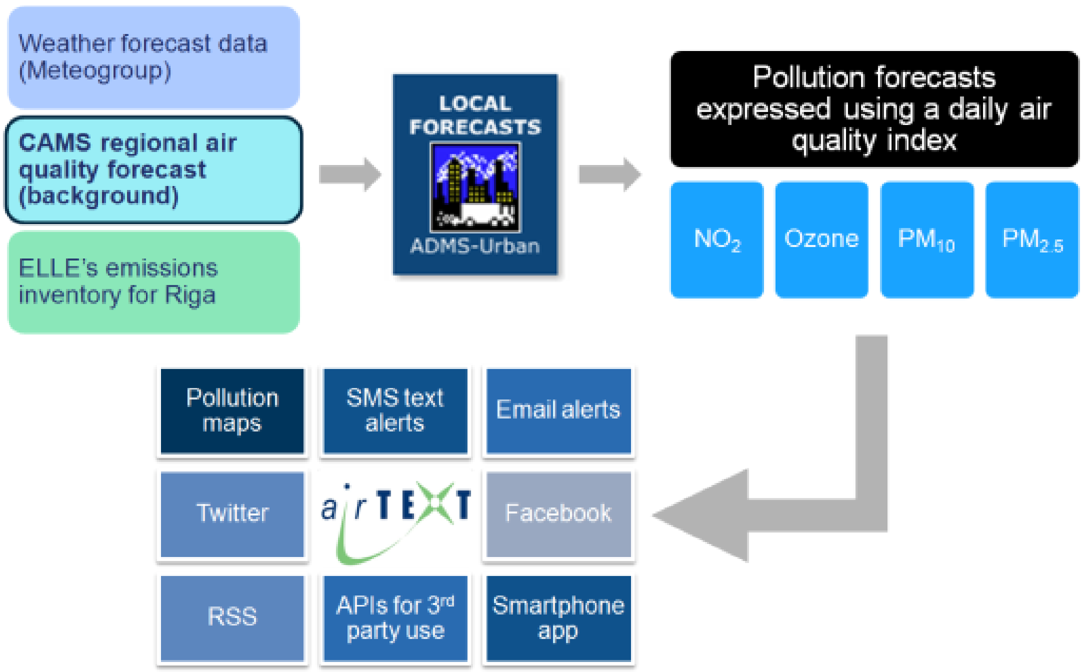


Figure 3-4: Representation of the data flow within Riga *airTEXT* service

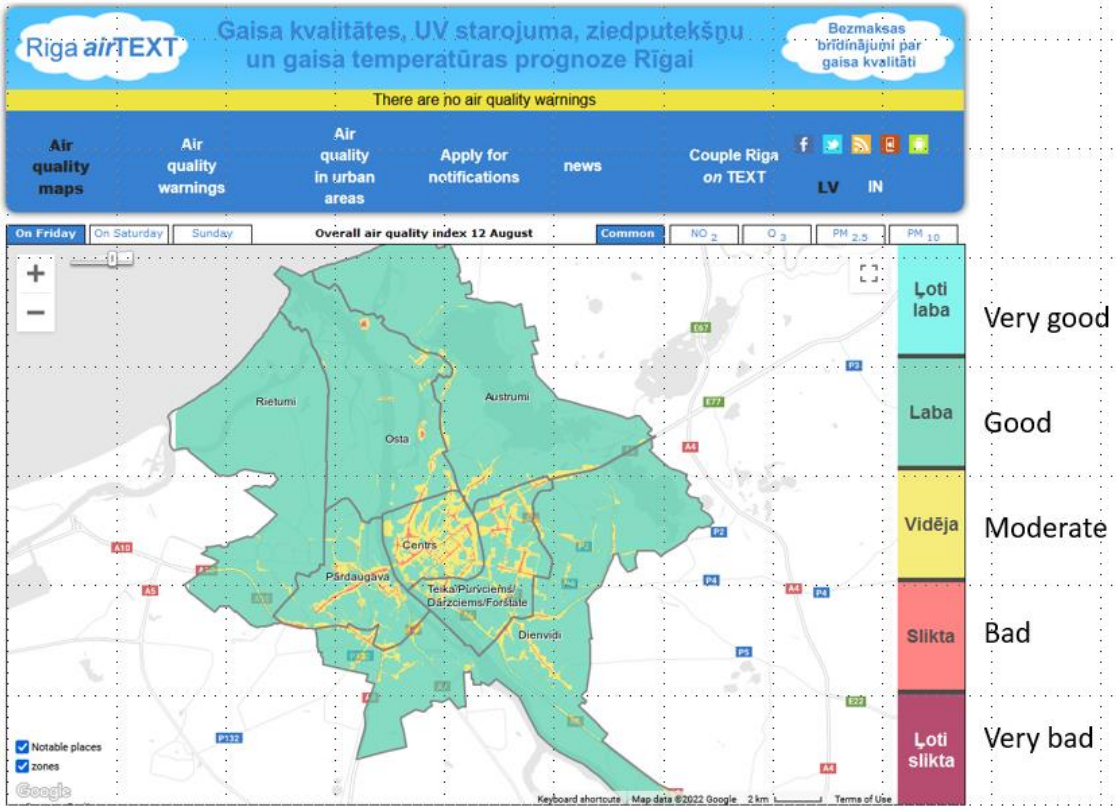


Figure 3-5: Overall air quality forecast in Riga for 12th August 2022.

This model is built for each city in which *airTEXT* is operating. The result is a highly detailed map of street-level air pollution, with more than 100,000 data points. The forecast made for the 12th August 2022 is shown in Figure 3-5.

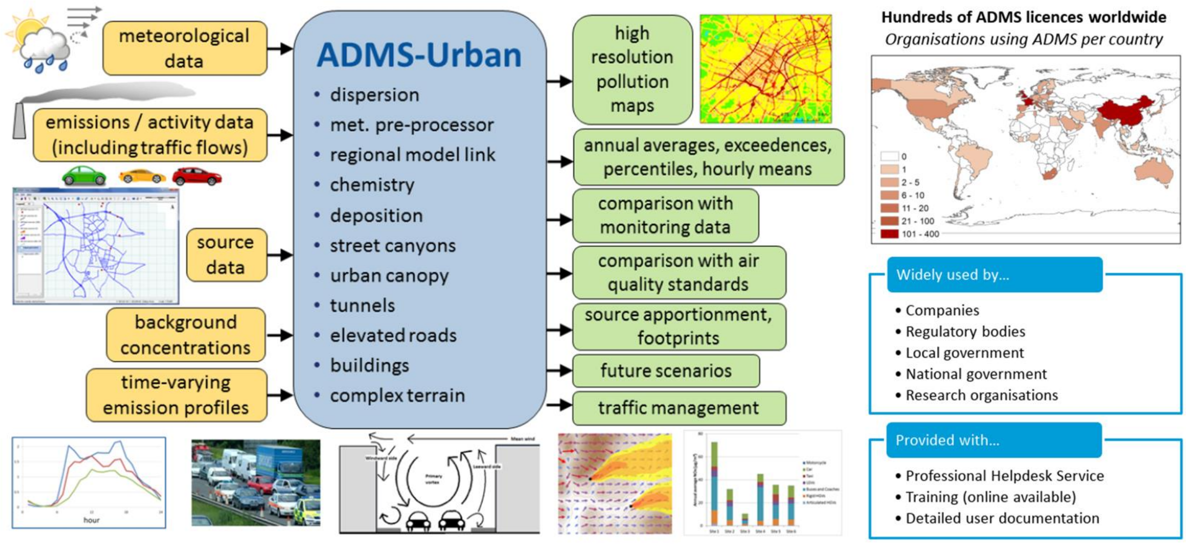


Figure 3-6: Representation of the ADMS-Urban model with key inputs and outputs.

To make the information more accessible to citizens, the concentrations of the different pollutants are converted into a daily air quality index (DAQI). The categories used differ slightly between London and Riga. The definition for the European Air Quality Index[30], following a 6-point scale, is shown in Figure 3-7, whilst the advice to citizens derived from this index is shown in Figure 3-8.

Band Descriptor	**O_3** 1-hour µg/m³	**NO_2** 1-hour µg/m³	**PM_{10}** Running 24-hour µg/m³	**$PM_{2.5}$** Running 24-hour µg/m³
Good	0-50	0-40	0-20	0-10
Fair	50-100	40-90	20-40	10-20
Moderate	100-130	90-120	40-50	20-25
Poor	130-240	120-230	50-100	25-50
Very Poor	240-380	230-340	100-150	50-75
Extremely Poor	>380	>340	>150	>75

Figure 3-7: Definition of scale for the European Air Quality Index.

3.4 Future Evolution of Air Quality Measurements and *airTEXT*

The air quality services are envisaged to evolve in two ways in the short to medium term. Firstly, in respect to the manner in which the information is made available through different channels. Secondly, in respect to the quality of the service.

CERC will work together with the boroughs and councils to improve the access to air quality forecasts. *airTEXT* continues to be supported by the public authorities and, recently, further investments have been approved coming from the UK Department for Environment Food & Rural Affairs (Defra) with a focus on how to improve the communication channels. *airTEXT* services have been provided through a dedicated app which has been promoted through local borough websites. Other experiences are showing that air quality information is best provided alongside other services such as weather forecasts.

Hence, the next phase of developments includes integrating the service with other apps on mobile phones more tailored to the specific user interests (ie health issues, schools, sports bodies etc), and to introduce new channels such as public billboards providing information in the street – for example next to bus shelters or the entrance to metro stations. Similarly in Riga, the city council is investing to improve the presentation of information as well as to publicise the availability of Riga *airTEXT*.

[30] For more information, please see the European Environment Agency webpage on the **European Air Quality Index**

Air Quality Level	General population	Sensitive people
Good	The air quality is good. Enjoy your usual outdoor activities.	The air quality is good. Enjoy your usual outdoor activities.
Fair	Enjoy your usual outdoor activities.	Enjoy your usual outdoor activities.
Moderate	Enjoy your usual outdoor activities.	Consider reducing intense outdoor activities, if you experience symptoms.
Poor	Consider reducing intense activities outdoors, if you experience symptoms such as sore eyes, a cough or sore throat.	Consider reducing physical activities, particularly outdoors, especially if you experience symptoms.
Very poor	Consider reducing intense activities outdoors, if you experience symptoms such as sore eyes, a cough or sore throat.	Reduce physical activities, particularly outdoors, especially if you experience symptoms.
Extremely poor	Reduce physical activities outdoors.	Avoid physical activities outdoors.

Figure 3-8: Advice recommendations for citizens (EEA)

Presently, the CAMS service is based on polar orbiting satellites data sources. Sentinel 4 comprises of two instruments which will be flown on the Meteosat 3rd Generation satellites planned for launch in 2024 and 2025. These will provide data to monitor air quality and particularly levels of NOX and Ozone. The significant difference will be the observation times since, from fixed geostationary orbit, measurements over Europe will be possible many times a day, unlike the existing satellites.

Many of the polluting gases are emitted from short-lived, essentially point-sources on the ground. Observations once per day risk to miss many of the polluting events. From geostationary orbit, this deficiency is overcome providing multiple samples each and every day. It is estimated that, if today 10% of the value is coming from satellite observation with 90% from in-situ data plus modelling, once Sentinel-4 is available, this ratio will be reversed for levels of NOX.

The quality and impact of the information is also subject to much research. The links between air pollution and poor health are not well understood and much of the work is about trying to improve this. Satellite data provides a wide-scale synoptic picture of levels of pollution which with public health studies can contribute greatly to improving our understanding. Three strands of activity linked to satellite data can be highlighted:

- The improvement of information coming through the *airTEXT* service by developing better models, integrating other data sources into the data stream; either directly as might be the case with particles driving asthma (pollen) or as inputs to models through better placed in-situ measurement stations.

  The service is also at the heart of further research into the links between ill health and air pollution. CERC are part of a team seeking funding to do a full clinical trial on the impact of air pollution on health. It is planned to be focused on a city in the north of England and includes aspects of behavioral analysis as people react (what information is helpful, how can it be presented, avoiding panic reactions etc).

  Some of the local boroughs in London; notably Southwark, Lambeth and Merton have received funding to adapt and improve *airTEXT*. Two strands of work are planned; firstly, to redevelop the database to improve the urban model and increase the spatial accuracy to a hyper-local level. Secondly, to develop new ways to get the results into the community. This includes to provide API's so that websites for schools, doctors or hospitals can include *airTEXT* data into their own information sources. Further, this will enable better diagnoses since the patient's illness can be correlated with air pollution levels in the locations where they have been. This could even lead to a reduction in medication and consequent savings. The work will start with "Discovery Research" to gather views of citizens directly.

- The use of AI to improve the measurement of air quality. Researchers[31] from Duke University have devised a method for estimating the air quality over a small patch of land using nothing but satellite imagery and weather conditions. Such information could help researchers identify hidden hotspots of dangerous pollution, greatly improve studies of pollution on human health, or potentially tease out the effects of unpredictable events on air quality, such as the breakout of an airborne global pandemic.

  Research has shown that extracted satellite image features can augment existing spatial predictors of $PM_{2.5}$.[32] The finest 200 m spatial resolution of ground-level $PM_{2.5}$ estimates is higher than the vast majority of existing state-of-the-art satellite-based $PM_{2.5}$ retrieval methods, and with an estimated performance at the high end of these state-of-the-art methods. The results highlight the potential of augmenting existing spatial predictors of $PM_{2.5}$ with high-resolution satellite imagery to enhance the spatial resolution of $PM_{2.5}$ estimates for a wide range of applications, including pollutant emission hotspot determination, $PM_{2.5}$ exposure assessment, and fusion of satellite remote sensing and low-cost air quality sensor network information.[33].

[31] Spotting Air Pollution with Satellites, better then ever before.
[32] Estimating ground level PM2.5 using satellite images by a convolutional neural network.
[33] Estimating ground level PM2.5 using satellite images by a convolutional neural network.

- A new programme by NASA[34], Multi-Angle Imager for Aerosols (MAIA) mission, scheduled for launch in 2023/2024, will combine the expertise of planetary scientists and epidemiologists to answer a question that, before now, has been largely impossible at a large scale: What kinds of air pollutant particles are most harmful to human health?

  MAIA will circle the globe in low-Earth orbit for 3 years, passing each target study area three times per week at the same local time each pass. To infer the composition of PM2.5, scientists will use the optical properties of particles measured by MAIA: the polarization of sunlight scattered by particles and images of the light at multiple angles in 14 electromagnetic wavelengths spanning from ultraviolet to short-wave infrared. Researchers will map PM2.5 concentrations and composition at the neighborhood level (a resolution of 1 square kilometer) in its 12 primary target cities in North America, Europe, Africa, and Asia. Atmospheric chemistry, spatial, and statistical models will integrate the MAIA data and information from ground-based monitors to output a complete picture of ground-level concentrations of PM and components of PM2.5 in the target areas.

34 Using satellite data to map Air Pollution and Improve Health.

4 Understanding the Value Chain

4.1 Description of the Value-Chain

The value chain for the case is shown in Figure **4-1**. The service is supplied by ELLE in close collaboration with CERC and ECMWF with the primary user or sponsor of the service Riga City Council. It is made available to citizens and organisations in Riga to enable them to make operational decisions based on the forecast.

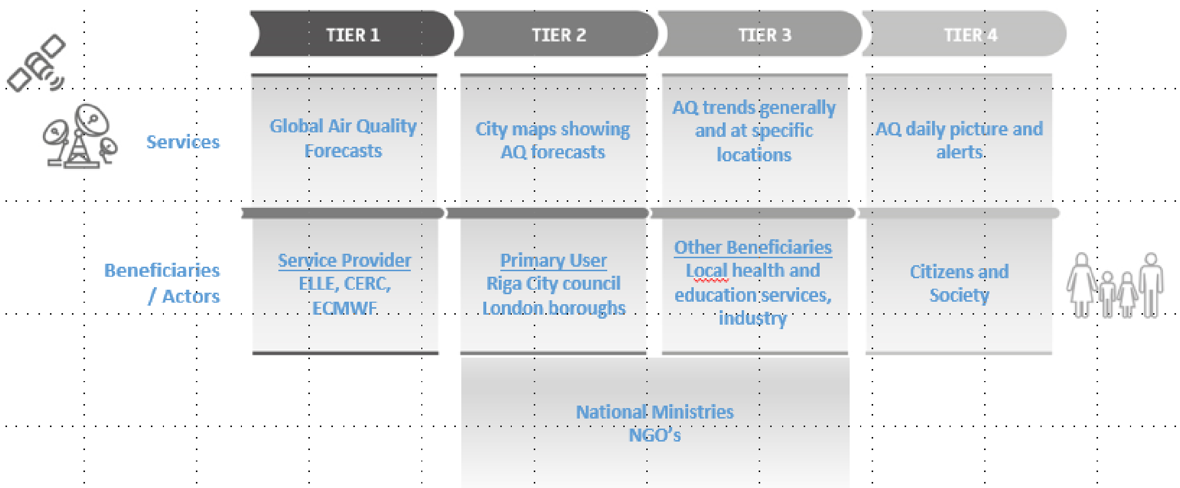


Figure 4-1: Value chain for Air Quality (AQ) Forecasts in Riga

The original *airTEXT* service has been developed by CERC in co-operation with a number of regional authorities in London (boroughs). These form the *airTEXT* consortium.

4.2 The Actors

4.2.1 Tier 1: Service Provider – ELLE, CERC, ECMWF

These three organisations provide the data and operate the models which produce the service in Riga.

Estonian, Latvian, Lithuanian Environment (ELLE).

The local service provider is ELLE which is an environmental consultancy based in Latvia, Estonia and Lithuania. Founded in 1998, ELLE now has 40 employees across the three countries.

ELLE provides environmental consultancy across different phases of the policy cycle. They support the governmental organisations which define and legislate for environmental policies. They support the planning associated with these policies in both public and private sectors. They support the assessment of policy implementation. Finally, they can audit the outcome of a policy and make recommendations for changes.

ELLE takes the lead in Latvia for the provision of the *airTEXT* service including the gathering and introduction of local data into the *airTEXT* models. In this respect they work closely with CERC which is the operator of the models of urban structures in Riga.

ELLE is licensed to supply ADMS software in the region. This includes the different versions of the software tuned to roads, airports etc.

Closely linked to this role, ELLE support Riga city council and the Latvian ministry to develop their strategic plans linked to air pollution.

Cambridge Environmental Research Consultants (CERC)

CERC is a consultancy company based in Cambridge UK. It provides software and services based on that software addressing environmental issues. Today, CERC has 20 employees and has both public and private sector clients in the UK, Europe and other countries.

CERC has developed and maintain a number of scientific models which are used for commercial business. The most well-known is the ADMS which is at the heart of *airTEXT*. Several versions of the ADMS exist focused on different types of environment. The ADMS is tailored with local data to enable forecasts of air pollution. Other models include EMIT (for atmospheric emissions), LSRS for liquid spills, and Flowstar-energy for wind modelling and wind turbine management.

CERC has conducted a number of studies for the UK government into air quality, atmospheric dispersions, wind flows and the effectiveness of relevant policies. In addition, CERC has been involved in a number of European R&D projects which have led to the *airTEXT* system. Most notably the projects PROMOTE which was funded through ESA as a precursor project to GMES the forerunner of Copernicus. PROMOTE was a programme on air quality and ultraviolet forecasting at the European, national and local scales.

The forecasts of regional background concentration that are used by ADMS-Urban make use of satellite and ground based measurements and a range of models for different spatial scales. ADMS-Urban is then used to provide high resolution local forecasts.

After this came PASODOBLE which was funded under the 7th European Framework Programme and to which CERC was a partner. This involved the development of a web-based air quality forecasting evaluation service. The partners of the project had goals to develop tailored air quality information *services including for* health community support services for people at risk, hospitals, pharmacies and doctors; public air quality forecasting for regions, cities, the tourist industry and sporting event organisers, *and* support services for compliance with the EU limit values for regional environment agencies.

The importance of reflecting different service needs for different communities is today a key element of ongoing research linked to *airTEXT* and has emerged from the feedback gleaned by several of the London boroughs. CERC also had a significant role in the public air quality support service through the development and use of the air quality forecasting system *airTEXT* with a focus on the London Olympic Games in 2012.

Today, CERC is concerned with operating the *airTEXT* service for London and Manchester in the UK, for Riga and Barcelona in Europe and for Beijing in China. In Manchester the service is provided through the Clean Air Greater Manchester website.

European Centre for Medium-range Weather Forecasting (ECMWF)

The ECMWF is an independent, inter-governmental organisation headquartered in Reading, UK and supported by 35 Member States. Established in 1975, it has over 400 staff located in Reading, Bologna (Italy) and Bonn (Germany). The latter houses those responsible for the Copernicus services. Along with ESA, ECMWF is one of the 6 international co-ordinated organisations.

ECMWF is a fully operational organisation providing numerical weather forecasts 4 times a day and forecasting global weather conditions from a few days to around 1 month in the future. It also conducts extensive research activities with the goal to improve forecasting and the uptake of its products. In this respect, it was a sponsor of *airTEXT* in the UK and also the introduction into Riga.

ECMWF's operational forecasts aim to show how the weather is most likely to evolve. To do this, the Centre produces an ensemble of predictions. Individually they are full descriptions of the evolution of the weather. Collectively they indicate the likelihood of a range of future weather scenarios.

To deliver these activities, the Centre provides:

- global numerical weather forecasts four times per day
- air quality analysis
- atmospheric composition monitoring
- climate monitoring
- ocean circulation analysis
- hydrological predictions
- fire risk predictions

ECMWF is a key partner of the European Commission within the Copernicus programme. ECMWF not only operates the Atmosphere service (CAMS) but also the Climate Change Service (C3S). At the heart of these services lies the ECMWF Integrated System Model (IFS) which is the model developed for numerical forecasting.

4.2.2 Tier 2: Primary User

Riga City Council

Riga is the capital and largest city in Latvia with around 630,000 inhabitants[35]. The city lies on the Gulf of Riga at the mouth of the Daugava River where it meets the Baltic Sea. The city was founded in 1201, more than 800 years ago[36].

After years of being part of the Teutonic empire, and ruled by Sweden, and Russia, Latvia was established as an independent republic in November 2018, following the end of the 1st world war. It fell again under firstly German and then Russian rule during the 2nd world war before finally regaining independence in 1991, after the collapse of the Soviet Union.

Riga is one of 7 state cities in Latvia with their own council and administration. Riga City Council is an elected body which takes care of the governance of the city. The administration is organised into 7 departments of which the Housing and Environment Department is responsible for environmental protection including the quality of the air.

In 2021, the city council agreed a strategic plan[37] in relation to air quality in the city. This follows an earlier Air Quality Action Plan from 2016 to 2020 during which sustained measurements of the air quality across the city have been made at 6 measurement stations. The measurements were used to calibrate the ADMS Urban model (from CERC), which takes into consideration local detailed emission inventory. Modelling and monitoring results indicated that a number of the EU recommended limits (assessment thresholds in this case, not limit values) have been exceeded on many occasions.

In relation to specific emissions the plan finds that:

- For NOX emissions, road transport (60%) and heating systems (individual and central plants) contribute mostly. Geographically, these follow the street patterns with a peak also in the port area.
- For PM^{10} emissions also follow largely the street network and are primarily caused by local transport and heating.
- $PM^{2.5}$ emissions are largely caused by the heating systems and follow the city districts where individual heating is dominant.

The strategic plan sets out the goal to reduce individual transport and increase the proportion of citizens using the public system such that the share of individual transport users falls from 52% in 2019 to 45% in 2025. If achieved this will reduce the number of citizens exposed to high pollution levels by 70% or even 92% in an optimistic scenario.

The plan includes several information systems to be updated and maintained including the further development of Riga *airTEXT* and specific actions such as days without cars, changing policy on domestic and central heating systems etc. A free pass to use public transport is foreseen for days when the pollution is forecast to reach high levels (“dust tickets”).

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35 Riga in Figures 2020: https://www.riga.lv/en/media/3958/download
36 History of Riga; https://www.riga.lv/en/rigas-vesture
37 Rīgas pilsētas gaisa kvalitātes uzlabošanas rīcības programma 2021-2025

Riga *airTEXT* was introduced in 2018 through an R&D activity and was endorsed by the Riga City Council and the Latvian Ministry of Environment. After a period of evaluation, the service has now received additional budget to continue its operation and increase the availability of the service.

London Boroughs- the *airTEXT* Consortium

The original *airTEXT* service was developed by CERC together with Croyden borough council in south London. Over the last few years. The service has been adopted by more boroughs to the point where today there are 38 boroughs which are partners to the service with several other organisations associated including the Greater London Authority, the Environment Agency and Public Health England. Together, these form the *airTEXT* consortium. The current leader of this consortium is Islington Council.

Commitment to the service has been growing and funding has continued and even increased as the number of partners has grown such that the operating costs are today covered by the consortium whilst further development is funded through a mixture of projects and stakeholders investing. Defra (Department for Environment, Food and Rural Affairs) which covers Environmental policy has provided a number of grants to users to establish services in their borough and help the system to evolve. Once such grant has recently been awarded to Southwark and Lambeth boroughs to develop *airTEXT* and to extend its reach into the community.

Discovery meetings are planned to gather the views of citizens and to shape the communication channels to maximise their engagement. Merton Council are establishing working groups to understand who needs what information.

Three "flavours" of *airTEXT* are envisaged, the first for the general public, the second for schools and the third for the healthcare community. Each is tuned to appeal to the respective communities. For example, in schools, the forecasts could be placed on a website which enables parents to communicate together. In each case, the goal is to make more people aware of the service and especially to target those who are vulnerable.

4.2.3 Tier 3: Secondary Beneficiaries

The *airTEXT* service in Riga and in London is available for many organisations to use in conjunction with their planning of activities. For example, in the UK, **Public Health England (PHE)** and the **Environment Agency** are both partners to the *airTEXT* consortium showing their interest to receive detailed information.

PHE was a national body tasked with protecting and improving health and wellbeing and reducing health inequalities. PHE was replaced in October 2021 with the UK Health Security Agency.

Potentially, the information is of use for schools to adapt the activities for the pupils on days when the air quality is poor and for hospitals to be alerted to the higher risk of patients seeking treatment for respiratory difficulties.

Health and emergency services are also using the service as reported in London by the mayor[38] as is Transport for London which operates the bus and metro services. Information is to be made available at all Tube station entrances as well as at bus shelters throughout the city.

The **Latvian Environment, Geology and Meteorology Centre (LEGMC)** is using the Riga *airTEXT* service along with outputs from the national monitoring stations, models, Copernicus (CAMS and imagery), the European Forest Fire Information System (EFFIS), and Saharel (Barcelona Dust forecast centre) to better understand the impact across the country. Currently, there are 11 monitoring stations in Latvia, but network is being modernised and optimisation will reduce this to 10 (for same results).

Data is monitored on a daily basis and provides internal reports identifying the level of risk. There is no mapping or forecast data made and all the data on the website is quasi real time. An alert is provided when it is considered the risk has become high.

Much of the air pollution across Latvia outside the urban areas is transboundary hence LEGMC is looking at forest fires in Russia, Ukraine as well as dust forecasts. An air quality prediction plan is generated every 4 years and currently recognises the problem of domestic heating.

4.2.4 Tier 4: Citizens and Society

The main users of the *airTEXT* service are individual citizens who are able to make more informed decisions regarding their daily lives. In London, a survey has been conducted on the views of users. This indicates a wide range of diverse organisations which have promoted the service to individuals including, their employers, health professionals and representative organisations. The broad range of sources indicates a wide reach but also that further promotion could be useful.

One of the findings of the survey indicated the fairly narrow demographic that is aware of the service and the very small proportion of those who are vulnerable who are signed up to receive the alerts. Current estimates are that only between 1 and 2% of the 30,000 vulnerable people are currently subscribed.

This highlights a problem of trust where the local authorities are perceived as being less trustworthy than local doctors or schools and is the reason behind the plan to expose *airTEXT* through different communication channels.

4.2.5 Other Beneficiaries

Latvian Ministry of Environment

Whilst in-situ measurements are more useful for determining policy, ie actual measurements, the number of measuring stations is insufficient and the data from *airTEXT* is used to help “fill in” the information on pollution and sources. Hence the granularity of information is increased.

[38] Air Quality Alerts to warn Londoners about Air Pollution, August 2016

This is achieved through modelling performed as part of developing the Air Quality management plan. It would be performed also without *airTEXT* but, in this case, *airTEXT* helps to understand the impact of "background" concentration better and triggers discussion on where this background pollution comes from.

A finer spatial resolution of pollution data is important when designing policies which can reach down to street-level such as for traffic flows and for heating systems in Riga. A better knowledge of the sources and their importance may greatly help policy design and implementation.

Baltic Environmental Forum

> *"Our goal is to promote the importance of environmental protection by developing cooperation and dialogue between different institutions and interest groups, and by improving their skills in implementing environmental management."*

The **Baltic Environmental Forum-Latvia (BEF)** is a non-governmental organisation established in 2003. The overall mission of the BEF is to strength environmental protection by developing co-operation and dialogue between various stakeholders. The focus of BEF activities is to foster implementation of the EU environmental policy in the Baltic Sea region. Since the establishment of the organisation classical themes such as water and land-use management have been a priority of the work program of the BEF. As an active NGO, the BEF promotes public and stakeholder engagement in river basin management planning an implementation. The BEF acts as a facilitator and networking organisation that seeks to build stakeholder capacity for better environmental protection. International and national events (seminars, trainings, info days) are organised regularly. BEF has experience in data collection and comparative analysis on different environmental issues, including landscapes and water. Several targeted publications and recommendations on EU policy implementation at various levels have been elaborated.

Defra – Department for Environment, Food and Rural Affairs.

The UK government department dealing with environmental issues has been a supporter of *airTEXT* since its inception. Defra provides an overall picture of UK air pollution as well as pointing to key resources. Defra has recently invested further in the development of *airTEXT* as well as communications about its access.

5 Assessing the Benefits

5.1 Overview

In this section we look at the benefits which are being generated through the use of *airTEXT*. We shall look at the impacts quite broadly and not just in economic terms – although these are the ones that most people are looking for. In our previous work, we have found that it is often the non-monetary benefits which are creating much of the value.

Our goal is to understand how much benefit is being generated through the use of data from the Sentinel satellites. In this we face a number of significant challenges:

- What is the cost of the problem to society of living in cities where the air is polluted?
- How much benefit is coming from knowing the level of pollution, today and the near future?
- How much can this change behaviour at the individual level?
- How many deaths or avoided hospitalisations can be the result of air quality forecasts?
- How much does Sentinel data contribute to this?

We have some answers to some of these points but not all and many assumptions will need to be made. Our analysis in economic terms will be based heavily on work conducted in the UK by the Royal College of Physicians[39] and the Committee on the Medical Effects of Air Pollution (COMEAP)[40]. We shall scale this to provide some figures for Latvia.

Where in the value chain?

Our normal approach is to establish benefits at each point of the value chain. But where should they be considered to fall in the case of air pollution?

The basis for our analysis is to measure the impact (the benefits) along a value chain. In most cases it is clear where the benefits fall. However, for air quality the benefit is created by the empowering individual citizens enabling them to improve their quality of life and preserving their capacity to work, whilst saving the cost of health treatment including hospital admission. The former will fall in tier 4 but where to assign the society benefit of reduced health costs?

Further, all analyses considering the cost of air pollution focus on premature deaths and the loss of working capacity for society at large. Logically, as it is a societal benefit, it should also appear in tier 4. But it can also be argued that it is benefiting the ministry or the state institutions which are saving money – in which case it could be assigned to tier 2 (primary user) or to tier 3 (other beneficiaries ie hospitals).

In this case, we have considered that the economic benefits are helping society at large and they are assigned under Tier 4.

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[39] Every breath we take (Royal college of physicians 2016)

[40] Mortality effects of long-term exposure to air pollution, COMEAP 2018

Attribution

Attribution is the relative importance of the satellite data to generating the benefits from the service. In this case, the extent to which data from satellites is contributing to improving the lives of citizens is a key question and one that is very hard to address. The satellite data is mixed with many other types of data (some coming from other, non-Sentinel satellites) and separating the relative importance of each one is a complex task.

The capability to forecast the concentrations of pollutants in the atmosphere is fully dependent on the numerical models used by ECMWF for medium-term weather forecasting along with specific analysis for CAMS. It is well accepted that these cannot work to any reasonable degree of accuracy without the satellite data.

The data from the Sentinels is detecting the levels of some of the key polluting elements. The numerical models allow the evolution of detected concentrations to be predicted for the days to come leading to the forecasts which can be used by citizens to adapt their behaviour accordingly.

Without Sentinel data, CAMS would not be able to provide reliable forecasts without the direct measurement of the contributing elements. These would be limited to extrapolations from point measurements by in-situ monitoring stations. This means the spatial accuracy would be very low.

We shall apply a level of attribution for the Sentinel data of 50%. i.e Sentinels are contributing 50% of the value which *airTEXT* generates.

Impacts of Air Pollution

Calculating the impact on society of air pollution is highly complex, hence our attempts to simplify in Section 5.2.

Firstly, there is the problem of how to measure the impact. As discussed earlier this is more usually done by assessing the loss of working life in DALY's (Death Affected Life Years) which is strongly linked to the death rate.

Secondly, the time lag between exposure to pollution and the death of an individual cannot be measured. Reducing air pollution affects the temporal pattern of deaths and leads to an increase in the number of years lived by the population in general. Statistical tables of life expectancy can be used to understand changes in age-specific death rates and to calculate effects on deaths, life expectancies and life-years lost.

A useful explanation is contained with detailed analysis in the report produced by COMEAP[4]on the mortality effects of exposure to poor air quality.

5.2 Analysing the Economic Benefits

Our methodology is normally based on estimating the economic benefits which accrue to each of the stakeholders along the value chain. However, in the case of air quality, this does not really work as all the benefits really appear at societal level. As a result, we deviate from the approach we have adopted in all previous case analyses to calculate a figure for these benefits. It has to be said that this calculation is already difficult enough to make without further complicating by trying to assign parts of it to the different actors!

We shall take three distinct approaches to this part of the analysis. The first is an estimate based on figures coming from the IHME[15]. The second comes from a study carried out in France and published in 2015[41]. The third is based on the cost of hospitalisations which can be directly affected by the use of alerts.

5.2.1 Valuing the Impact on the Economy

A great deal of uncertainty surrounds the estimation of the cost associated with exposure to air pollution. Firstly, the uncertainty in the relationship between the exposure to pollutants and the impact on health given each individual reacts differently and the effects are often not visible until after a long delay between exposure and effect. Secondly, is the problem to understand the exposure of individuals since this varies by day and by location. Thirdly, the effectiveness of care needs to be taken into account. For all these reasons, the cost or impact estimation is usually linked back to mortality and the number of healthy days lost as a result of premature deaths.

Non-fatal health outcomes are excluded from the scope of analysis for two reasons. First, morbidity makes up a very small share of the total health impacts of air pollution as estimated for GBD 2019[15], and regulatory analyses of air pollution control policies in the United States and elsewhere have consistently found that the majority of economic benefits accrued by improving air quality take the form of avoided premature deaths[20].

Excluding morbidity costs does not significantly influence the overall magnitude of the cost estimates, although nonfatal outcomes may represent at least another 10 percent of total costs (Hunt et al 2016). Second, unlike for morbidity costs, a standard framework exists for valuing fatality risks that is supported by a well-developed body of economic theory and empirical studies[42].

This leads us to the Global Burden of Disease published by the IHME[15] which provides estimates which are widely accepted and are used as the basis for estimating the cost impacts. Results have been compiled into a dedicated report on air pollution[16] in which figures are provided for 180 countries. The figures for Latvia and the UK, as well as a few selected other countries for comparison, are reproduced in the Table 5-1 below.

Country	Excess deaths due to air pollution		Total welfare loss $m, %GDP	
	1990	2013	1990	2013
Latvia	2,605	1,407		3,482 8,1%
UK	45,453	19,803	131,836 8,8%	76,694 3,2%

[41] Rapport fait au nom de la commission de l'enquete sur le cout economique et financier de la pollution de l'air. Publie juillet 2015.
[42] Methodology for Valuing the Health Impacts of Air Pollution; Narain & Sall, 2016

France	27,464	21,138	87,942 5,1%	81,840 3,3%
Belgium	7844	5858	25,788 8,5%	24,190 5,3%
Germany	71,136	41,485	240,370 9,6%	180,099 5,2%
US	127,240	91,045	490,953 5,3%	454,675 2,8%
China	1,518,942	1,625,164	126,592 7,3%	1,589,767 9,9%
India	1,043,182	1,403,136	104,906 6,8%	505,103 7,7%

Table 5-1: Societal costs of air pollution for selected countries (source IHME[16]).

For Latvia, the number of premature deaths has almost halved since 1990 whilst the associated welfare costs, calculated from the DALY is around 8.1% of the GDP at $3,5b. In the UK, the total, overallcost is estimated to be $76b with almost 19,800 lives lost prematurely. This figure is less than that given by UK reports which identify 29,000 premature deaths due to ambient air pollution[16]. We are using the numbers from the World Bank/IHME report[16] to provide a more robust comparison with Latvia. This report also estimates an impact of €600b across the whole of Europe.

For comparison, a study led by the Aarhus university[43], finds that the economic costs of air pollution in Europe are €300b per annum. This would suggest a lower figure (approximately half) than the IHME assuming a scaling across Europe based on GDP.

The team at Aarhus have developed a model EVA (Economic Valuation of Air pollution). The model system, as shown in Figure 5-1, can be used at different scales by coupling with the appropriate air transport model (ie European, country or city models) and includes gridded population data, exposure-response functions for health impacts in terms of morbidity and mortality, and economic valuation of the health impacts from air pollution.

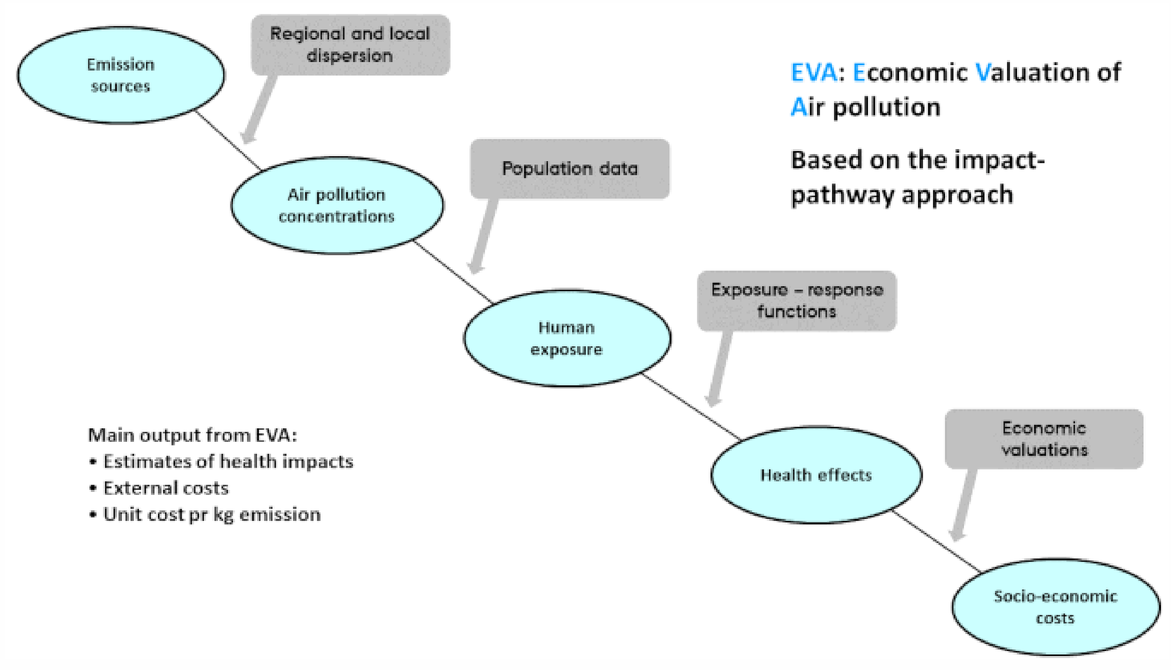

Figure 5-1: Aarhus model[43] for the Economic Valuation of Air Pollution (from University of Aarhus).

An alternative perspective is given in the UK. The British Lung foundation[44] calculates that the cost of respiratory diseases amounted to £11.1b in 2014. This includes £9.9b of direct costs (treatment, medicines, hospital stays etc) and £1.2b of indirect costs (days lost from work). Since this is only concerning lung disease it is a significantly lower figure than that calculated by the IHME, plus it is not based on early deaths which most other studies are.

Another source from the University of Leicester[45], provides the figure that air pollution in the UK costs the economy between £9b and £20b. Whilst not directly comparable with the figures above for deaths from respiratory diseases, they each give a view on the scale of the problem which are of the same order.

These different analyses provide an overall figure for the cost of disease for which air pollution is one component. There is also the problem of avoided consequences. In this case, the numbers associated with avoided deaths, hospital admission or illness for which only statistical methods can approach the desired result.

Hence, we are still left with the challenge to make the link between the costs to society and the savings which may be achieved through the use of warning information systems like *airTEXT*. Here, research is lacking and, whilst the links between air pollution and illness are well established, and the benefits of avoiding breathing severely polluted air are clear, placing numbers on this benefit is challenging.

[43] Economic Valuation of Air Pollution; University of Aarhus.
[44] The Lancet, Economic cost of respiratory disease, 2017
[45] Air Quality Remote Sensing: research project

In the absence of precise (or indeed, any) numbers, we fall back on making assumptions. We could assume for instance that 1% of the "cost" could be saved through the use of *airTEXT* information. This would lead to a figure for the economic benefit in the UK of $760m and for $35m in Latvia based on the IHME analysis - Table 5-1). These numbers "feel" too high, but we can reduce them by reducing the number to 0.1% (1 in 1000) which gives $76m and $3.5m respectively. These seem more realistic but still rather high.

If we were to take the lower figures coming from the other sources for the cost of air pollution in the UK, we should roughly divide by a further factor of 10 taking our economic benefit to $7.6m in the UK and $350k in Latvia. To this will be applied the estimate that 50% of the benefit of using *airTEXT* can be attributed to Sentinel data.

5.2.2 Evaluation of Health Impacts

The report commissioned in France and published in 2015, sets out the uncertainties associated with this analysis. These are identified as:

- Links between exposure and the degree of risk to an individual
- How much has an individual been exposed to poor air,
- The uncertainty surrounding the attribution of the causes of death or disability to air pollution.

A structure for evaluating the costs is set out in terms of health costs / non-health costs, and direct costs as well as those indirect. For example, the cost of hospitalisation and other healthcare costs are direct, the morbidity cost or mortality cost is indirect. The structure for this analysis is represented in Figure 5-2, with elements translated from the original chart in French.

The commission sets out to establish the economic costs for each of these elements which it evaluates:

- Direct health costs are estimated at €3b per annum.
- Indirect costs are estimated at:
    - €20-30b each year by the CGDD (Commission General de la Developpement Durable)
    - €50b by the WHO and OECD
    - €70-100b by the EC programme, Clean Airs for Europe.
- The non-health costs are estimated at €4.3b recognising that no authoritative study has been carried out into this element.

The commission considers that these figures underestimate the true costs! It is notable that whilst the UK study referred to earlier considers the direct costs to be higher than those contained in the French report, the indirect costs are considerably less, and the overall result is about twice as high in France as in the UK although similar to the costs coming from the University of Leicester.

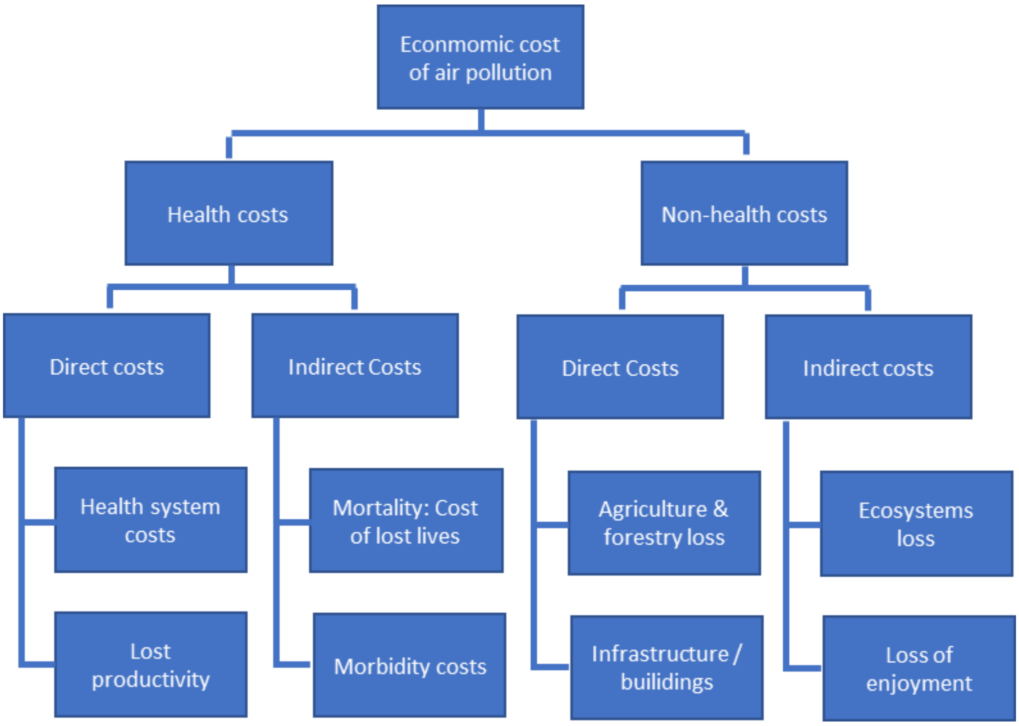

Figure 5-2: Representation of the costs of Air Pollution (based on Report of the French Commission[41])

This is unlikely as, although the system differs the overall costs, at least for a similar population size should not differ significantly.

There is no analysis which relates to the effectiveness of alerts, and we are bound to return to the rather crude approach of attributing a percentage of costs that can be saved. If we take the WHO / OECD figure of €50b, with the other "costs" we arrive at a total impact of €57b which is not so far from the 76b we have used as a total overall cost in the UK. The populations are quite similar and we use this to confirm the figures calculated in the UK.

5.2.3 Cost of Hospitalisations

A number of studies have looked at the increased risk of hospital admissions due to air pollution[46]. In the UK, 840,000 out of 12.5m admissions in 2021 were linked to respiratory conditions (NHS Digital Hospital admitted patient care by diagnosis for 2020-2021). The median length of stay was 4 days[47]. Not all of these are due to ambient air pollution.

As part of a wider study into the benefits coming from UK investments in space, a case study[48] looked at the benefits of an alternative air quality service with the conclusion that it could save

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[46] Effect of air pollution and hospital admissions; A systematic Review.
[47] NHS England. https://www.england.nhs.uk/statistics/statistical-work-areas/
[48] UK Space Agency, returns and Benefits from Public Investments 2021

£4.1m per annum through reduced emergency admissions to hospitals. No methodology for calculating this figure is presented.

Hospital costs vary greatly by country and even within countries. In the UK and average intensive care cost is £1328 per day whilst the cost of a bed on the ward is £195[49]. Total costs are higher taking into account specialist treatment. Taking an average cost of a hospital stay as €500 per day or €2k per stay, the study implies that some 2200 admissions are avoided each year through the use of air quality information. This only accounts for the direct cost of admissions and does not account for the total value loss to society as calculated by the IHME.

Now let's make a direct calculation for Latvia and for Riga. To estimate the potential benefits from early warnings on increased PM2.5 concentrations, we have made an estimate of the number of potentially prevented hospitalizations with cardiovascular diseases in Riga in the one year time frame 2021-09-26 -- 2022-09-26:

In 2016 the population of Latvia was 2 000 000 people[50]. The total number of 'incidents' of serious cardio-vascular diseases per year in Latvia[51] is 317 (133+36+149) per 100,000 = 6,340 and per day is 17. Here we assume that each 'incident' requires hospitalization. The population of Riga is 742,572 (2022, World Population Review) and hence on the same logic the average number of hospitalisations is 6.3 per day.

Counting "polluted days" in a year time frame[52] where (as in a study from Finland[53]) PM2.5 > 20 ng/m3 from the Copernicus Atmosphere Monitoring Service (CAMS) analysis dataset, the number of PM2.5-polluted days is 33.

Each time we assume there is a percentage increase in the daily number of hospitalizations equal to the numbers presented in the Finnish study i.e. (-3.5 + 4.7 + 2.6 + 2.0 - 0.7) = 5.1 % for cardiovascular illness.

So, the total increase in hospitalisations due to PM2.5 pollution would be then estimated as being: 33*6.3*0.05=10.4 additional hospitalizations in Riga each year. The average stay (from UK figures) is 4 days, and the average cost of each hospitalisation is €2k, yielding a potential saving of €20k through reduced hospitalisations for cardiovascular diseases.

Making similar calculations for asthma driven respiratory illness leads to a figure of 20 additional hospitalisations in Riga[54], or a cost of €40k that can be potentially saved. Hence €20k+€40k=€60k for Riga.

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49 https://associationofanaesthetists-publications.onlinelibrary.wiley.com/doi/pdf/10.1111/j.1365-2044.2007.04997.x

50 World Population Review, https://worldpopulationreview.com/countries/latvia-population

51 https://doi.org/10.34172/ijhpm.2020.229 (see Supplementary file 2).

52 Here we used the time span 2021-09-26 -- 2022-09-26.

53 http://dx.doi.org/10.1016/j.envres.2016.08.003 (Table 4, p. 5)

54 The number of hospitalizations with asthma in Latvia is 119 / 100 000 (see State of Health in the EU: Latvia. The respective percentage in hospitalization increase for asthma on a polluted day is

Considered for the whole of Latvia, the total number of avoided hospitalisations is 76 with an associated cost of €152k. As a comparison, the estimate for the UK, given in the aforementioned analysis[48], is £4.1m (€4.7m) for a population of around 65m which would scale to around €135k for Latvia.

To complete the figures, taking the population of London as 9m, and scaling for the UK, leads us to consider that the cost in London alone is 9/65*4.7m=€650k.

The above are the estimates for *airTEXT*. As stated earlier, we shall use 50% of this as attributed to the Sentinel data being used. This is applied in Table **5**-**2**.

This approach is also used by the US EPA in their BenMAP-CE model. Their analysis is based on a cost of each hospitalisation of $5k[55] so some 2.5 times the cost we have used in Europe. Given the general differences in health care costs between Europe and the US, we shall use the more conservative value of €2k set out above.

A further factor which we have not included in the economic calculation is the benefit to hospitals to improve their planning. Knowing that a peak of air pollution is expected in the next few days, allows some additional capacity to be reserved by postponing non-urgent operations, or increasing medical staff availability. As air pollution forecasts become more mainstream, as they undoubtedly will, will improve this capability.

5.2.4 Summary of Economic Benefits

Two distinct methods have been investigated with which to estimate the economic benefits. The first starts with broad figures for the societal cost of air pollution coming from IHME/WB reports (starting with the Global Burden of Disease). However, to ascribe a part of this as being avoidable through the use of *airTEXT* services requires large assumptions to be made with little justification ie 0.01% to 0.1% can be saved.

The second method is based on estimating the narrower result of avoiding emergency hospitalisation entries. The summary of these figures is given in Table **5**-**2**.

Putting all this together, the assumptions made do lead to very wide variations in economic benefit with the view that the numbers are not very robust. Nevertheless, comparing the two methods, there is a good correspondence between them at the lower end of the estimates from method 1. Finally, the first two columns relate to *airTEXT* and in column 3, the attribution of 50% of the value as a result of using Sentinel data is applied.

(11.3 + 6.4 + 15.8 - 4.9 - 2.6) = 26.0 % (see Table 4, p. 5 in http://dx.doi.org/10.1016/j.envres.2016.08.003).
Hence, the total number of hospitalizations increase with COPD/asthma in Riga would be 119 / 100000 * 742572 / 365 * 33 * 0.26 = 20.

[55] How BenMAP-CE estimates the Health and Economic Effects of Air Pollution.

	Method 1 based on societal welfare loss (€)	Method 2 based on avoided hospitalisations (€)	Figure used as annual benefit due to the use of Sentinel data. (€)
Riga	135k – 1.4m	60k	65k
Latvia	350k – 3.5m	152k	175k
London	1.1m – 11m	650k	325k
UK	7.6m – 76m	4.7m	3.8m
Europe	60m – 600m	52m	30m

Table 5-2: Summary of Estimated Economic Benefits at different geographical scales.

This leads us to conclude that, if we are to put a figure for each country, then €175k in Latvia and €3.8m per year in the UK are not unreasonable numbers for the benefit arising from the use of Sentinel data to provide air quality forecasts and to combat health impacts of poor air quality.

Finally, can we extrapolate to the European level? From the global (WB) report[16], the estimated welfare cost for Europe is €600b. Globally, an extrapolation is unreliable due to the large variation in pollution and death levels particularly in Asia. However, the variation of pollution levels and deaths between European countries is much lower and we consider that an extrapolation across Europe is feasible.

Based on method 1, this gives us an estimated annual economic benefit of between €60m and €600m for Europe. Based on method 2, we arrive at €52m and so an *airTEXT* benefit of €60m and that from the Sentinel use of €30m.

5.3 Benefits along the Value-Chain

5.3.1 Tier 1: Service Provider – ELLE, CERC, ECMWF

The three organisations which work together to supply the *airTEXT* service are each benefiting in different ways:

ELLE is the local company. ELLE is able to cover its direct costs through the service contract with Riga City Council. ELLE supports the council in monitoring the impacts of legislation and preparing new regulations. As such, the main benefit for ELLE is sustaining their position as a key advisor to Riga and to the Latvian Ministry of Environment.

CERC receives a small service fee for running the models and providing the data for Riga. Riga *airTEXT* is benefiting CERC in 3 main ways:

1. Being one element of the *airTEXT* service which is offered by public authorities as a local service to their citizens. As further clients are signed up the marginal cost of serving each becomes smaller. Even so, direct revenues from *airTEXT* form a part of CERC business.

2. Underpinning the role of CERC as a research organisation and advisor to their clients. Operating the *airTEXT* service provides data and insights which enable CERC to build their wider business.
3. It also helps build their business relationship with ECMWF.

ECMWF benefits through the use of its service so maintaining its reputation for high-quality services and fulfilling its social mandate. This helps further to underpin their role as an Entrusted Entity for the EC and contribute to the overall goal of enabling European business through exploitation of the Copernicus system.

CERC in co-operation with some of the users has also been successful in winning research grants not only linked to *airTEXT* but also to understanding the impacts of poor air quality. In late 2022, they are awaiting news on a major research project to examine the impacts of air quality on health including the impact of *airTEXT* and behavioural analysis relating to the benefits (or otherwise) of users having better information on the air quality and how they react.

5.3.2 Tier 2: Primary User – Riga City Council

The *airTEXT* service has helped the Riga council develop and implement policies linked to cleaner air in the city. This includes the development of a 3rd workplan effective from 2021 to 2025 which has led Riga to adopt policies linked to:

- Establishing low emission zones, restricting access, banning older and/or higher polluting vehicles.
- Creating cycle tracks as a means to encourage citizens to bike around and reduce the number of car trips.
- Change to home heating to reduce individual stoves in favour of cleaner heating forms as well as collective heating systems.
- Coal dust has been reduced by moving the facility to the other side of the river with less pollution in the city.
- Providing free public transport on high-risk days. Riga has introduced a "dust ticket" for use when alerts are high.

How much does *airTEXT* contribute to these policy decisions? This is quite complex, and it is probably fair to say that it is not *airTEXT* which makes them possible. Rather, the ADMS-urban model is used to increase the granularity ie the spatial sampling of the measurements and provides the necessary data. Riga *airTEXT* is hence made possible due to the investment made into the ADMS-urban 5.0 modelling. This allows the Riga City Council to develop its Air Quality Management plan as well as providing the service to citizens to demonstrate its commitment to improving air quality.

As a result, 4 benefits can be identified stemming from its use:

- The ability to investigate the impact of possible policy measures in zones with low levels of pollution. The higher resolution provided by the ADMS-urban model and *airTEXT* allows trends to be followed which would be difficult to see with larger scale measurements even if they are more precise |(in-situ). This in turn allows impacts of changes to be visible more quickly and with more sensitivity than would otherwise be the case.

- Having better data allows more effective discussion on the policy measures. Evidence of the effectiveness of changes can be produced to re-enforce the debate around new policy. It enables the city council to convince others that these measures should be taken.
- Riga *airTEXT* provides a visible demonstration of the commitment of Riga city council to improve air quality for the citizens and to offer them a better service.
- The availability of air quality indices has raised awareness of the Copernicus programme and what it can bring to Latvia. Other organisations, for example the Latvian Meteorological Institute have increasingly connected with the Copernicus programme following the introduction of the Riga *airTEXT* service.

London Boroughs

The introduction of the *airTEXT* service in London has resulted in many of the boroughs joining the consortium and working together to improve air quality. In the UK the Government sets out air quality standards and objectives in an Air Quality Strategy and within London, the Mayor's Air Quality Strategy, for which the Mayor has a legal responsibility, sets out a framework for delivering improvements to air quality. Up to the present, these have largely followed EU regulations.

The strategy has now led to reports being produced under the London Local Air Quality Management Plan[56] where each borough is required to produce an annual status report. Each of the borough councils with which we spoke have an action plan and a status report:

- Merton (London Borough of Merton Air Quality Annual Status Report for 2021)
- Southwark (Southwark Council Air Quality Annual Status Report for 2021)
- Islington (Islington Air Quality Annual Status Report 2021)

This has led to many restrictions to be introduced for both public and private transport means, E.g. taxis where any vehicle over 15 years old is refused a license to operate and for electric vehicles which are encouraged by not having to pay the London congestion charge. London buses are also changing with the introduction of hydrogen powered buses which are put into service on the most polluted routes.

airTEXT is an enabler for these policy decisions providing a more detailed picture of pollution across the capital and is strongly recognised in the London Air Quality Strategy and each of the borough action plans where support is provided.

The *airTEXT* consortium oversees the operation and evolution of the service which is operated by CERC. This has provided a platform through which the boroughs co-operate to reduce air pollution.

56 London Local Air Quality Management policy guidance 2019

This provides a platform for best practice and sharing knowledge amongst all the consortium members.

The healthcare system has been identified as one of the most important for making *airTEXT* information available and building the trust of citizens for its use. The local authority is able to improve its reputation through addressing wider action plans for example the London-wide plan to improve air quality[57] published in 2010. Local action plans are backed up by periodic reporting, for example in the City of London annual air quality status report[58]. Encouraging doctors to make their vulnerable patients more aware of air pollution and the effect on their health is given a poignant twist by the report into the death of a young girl Ella Adoo Kissi Debrah[59] in 2013 (see text box).

In his report, the coroner, Philip Barlow stated that "*there is low public awareness about air pollution. Greater awareness would help people reduce their exposure to air pollution. The issue needs to be available at a national as well as a local government level including increasing capacity to monitor air quality*".

This report is notable as being the first time a formal death report has included air pollution as a contributing factor.

5.3.3 Tier 3: Secondary Beneficiaries

In addition to the local citizens, the service is also used by local businesses and public services. Regrettably, we have not been able to interview any of these secondary users and are relying on discussions with primary stakeholders.

Nevertheless, we understand that *airTEXT* has been promoted through hospitals, pharmacies especially centres dealing with Asthma to make their patients aware of the service. Then local businesses and public services are encouraged to make employees aware of the service as a means to protect their health. Transport London are making the alerts visible at the entrance of certain metro stations.

Taking these actions is of limited benefit to the secondary actors. The hospitals and doctors can potentially reduce some costs for medicines, largely by avoiding unnecessary prescriptions, and maybe have an influence over patient loads which can reflect in improved performance measures. *airTEXT* offers them an evidence tool to help better inform their patients and provide more convincing diagnoses. But overall, it is about helping their patients through community services and consequently is a contribution that they make to society.

[57] Clearing the Air; The Mayor's Air Quality Strategy. 2010.
[58] City of London Corporation, Annual Air Quality Status Report, May 2022
[59] For the full story of Ella see: https://ellaroberta.org/about-ella

Ella's Story

Energetic and fun-loving, Ella was born in 2004 in London. Three months before her seventh birthday, she developed a chest infection that turned into a persistent cough. It sounded a lot like whooping cough, but a doctor diagnosed her with asthma. Rosamund, her mum, didn't initially worry at the mention of this common childhood complaint - 5.4 million people in the UK are asthmatic, 1.1 million of them children.

That changed when, soon after the asthma diagnosis, Ella coughed so much she blacked out; she had suffered a 'coughing syncope' caused by lack of oxygen to the brain. Fortunately, a neighbour with first aid skills was on hand to resuscitate her. She was admitted into hospital and released the following day, but a week later it happened again. This time she was put in a medically induced coma and woke up three days later. She went from being a happy, healthy child to being disabled by asthma.

The next two years were filled with a barrage of tests to find out what was causing Ella's ill health. These multitude of examinations only revealed she was atopic (sensitive to allergens) but couldn't ascertain the cause of her asthma. In September 2012, the coughing returned, and Ella was in and out of hospital.

On 15th February 2013, just three weeks after her ninth birthday, Ella died of a fatal asthma attack.

She had over 30 emergency hospital admissions between the first diagnosis of asthma and her death, just over two years later. Throughout her short life and illness, there had been no mention of air pollution being a possible factor in relation to her illness, and that this could be an asthma trigger, alongside traditional triggers such as pollen or the weather.

After a piece was published in the local paper a neighbour suggested she should; "have a look at the air pollution levels on the night Ella died". Rosamund discovered that the heavily congested road, near where they lived, had illegal levels of nitrogen dioxide caused by traffic.

Because of the new evidence, a new inquest, in December 2020, looked at the role air pollution played in her death. It examined what government departments and local authorities had done to reduce illegal levels of air pollution where Ella lived. It became apparent that throughout Ella's life, nitrogen dioxide emissions in Lewisham exceeded both EU and national levels and particulate matter levels were above the World Health Organisation (WHO) guidelines.

At the end of a nine-day inquest the Coroner, Philip Barlow, concluded that "Air pollution was a significant contributory factor to both the induction and exacerbations of her asthma. The principal source of her exposure was traffic emissions, which possibly contributed to her death. Ella's mother was not given information about the health risks of air pollution and its potential to exacerbate asthma. If she had been given this information, she would have taken steps which might have prevented Ella's death".

Text from the Ella Roberta Foundation. https://ellaroberta.org/about-ella

We also found evidence that the service, and indeed the use of Copernicus, is promoting greater awareness and communication between different organisations. Having a common source of data and information is promoting comparisons between some of the different players in healthcare which in turn is also helping to raise the political awareness as noted amongst the primary users.

5.3.4 Tier 4: Citizens and Society

Unlike most services based on EO data which are targeted on B2G or B2B "markets", the principal users and beneficiaries of *airTEXT* are citizens and society. As has been described, the primary beneficiaries of the *airTEXT* service are those persons living in urban areas and who have a vulnerability to air pollution. This concerns many millions of people; estimated at around 5.4m in the UK[60] and some 80k in Latvia[61]. The alerts received from the service enable them to adapt their behaviour to the actual and forecast air quality.

The best evidence for this (apart from the tragic story of Ella) comes from a user survey conducted by Southwark Borough Council and the *airTEXT* consortium in London. The questionnaire was sent to 5,683 subscribers to the service by email or by text alert and who had agreed to be contacted for the survey. Out of 507 *airTEXT* subscribers who responded to the survey:

- 97% said that *airTEXT* increases their awareness of high pollution days
- 87% said that when they receive an *airTEXT* alert they take action to reduce their pollution exposure
- 94% say that *airTEXT* is useful to them with 66% saying it is very useful.
- 98% say that they or someone who they care for suffers from a health condition adversely affected by air pollution.

This is a very positive picture but is conditioned by replies coming from both users of the system and those motivated to respond to the survey. Over 90% of those responding reported that they or someone who they care for, has a health problem and that the service helps them manage this.

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60 Asthma and Lung UK

61 Public Broadcasting of Latvia.

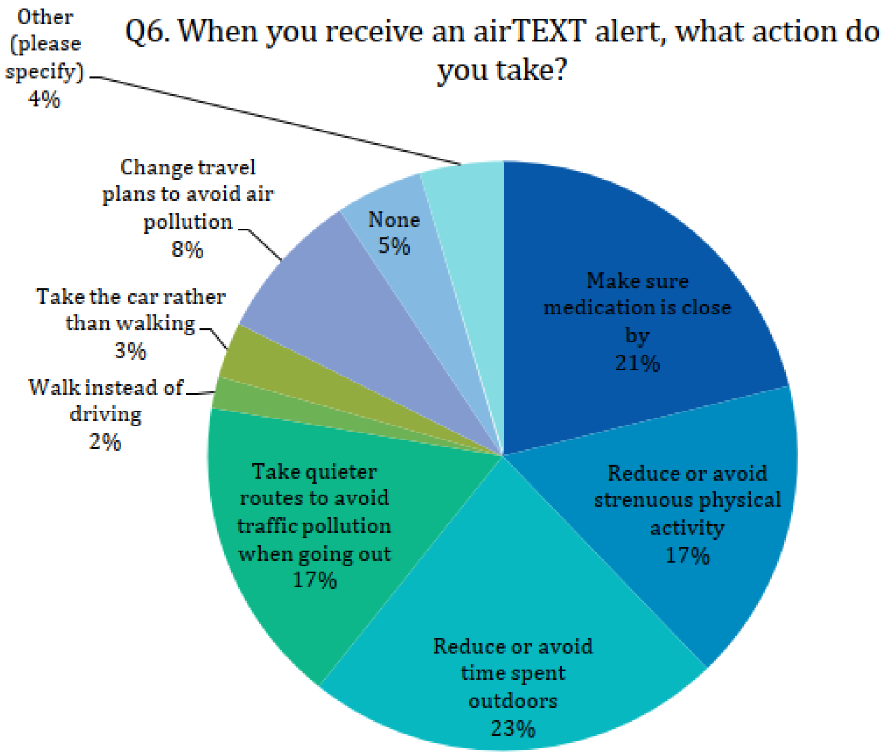


Figure 5-3: Actions taken by users of *airTEXT*.

The sorts of action that are taken are shown in Figure 5-3. Clearly *airTEXT* is providing a service which improves the quality of the life of the people using it and those using it are vulnerable to adverse effects.

The service is free at the point of use with the operational costs covered by the borough or city council. We can pose the question as to how much people would be willing to pay if it was not free? However, as a broad public-health issue, public support for the service seems fundamental, necessary and relevant.

In December 2010, when the London Air Quality strategy[57] was produced, the target was set to have 250,000 users within 5 years. Now, even some 12 years later, estimates suggest that only around 25,000 people are using the service. Hence the emphasis on improving communications and the ways to push information to those at risk.

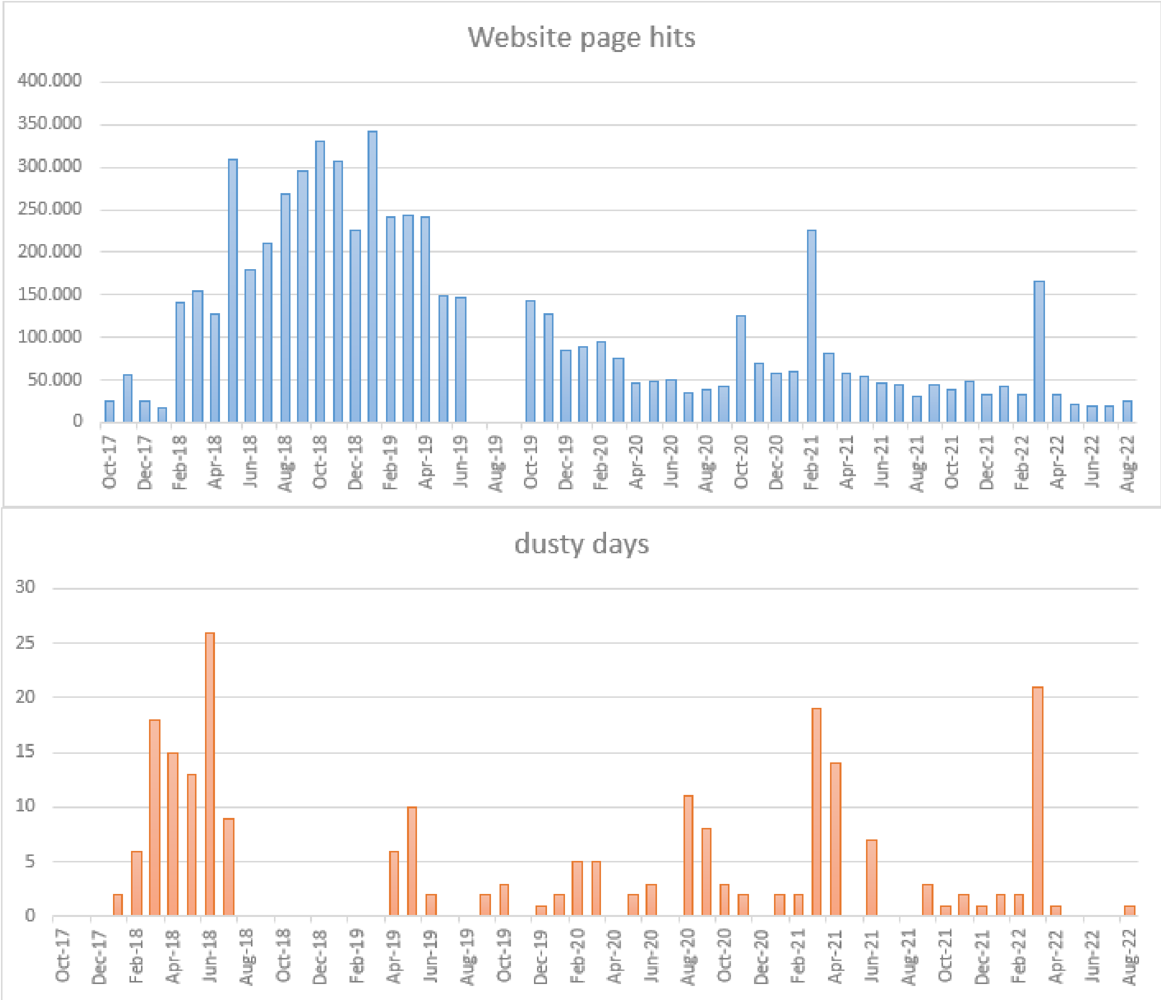


Figure 5-4: Use of Riga *airTEXT* compared with the number of dusty days.

In Riga, the number of users accessing the site is registered through the number of page hits. This is shown in Figure **5-4** for the period October 2017 up to August 2022. The interest in the service is seen to peak in 2018 after it was first introduced with around 300,000 visits in the month which has fallen away to around 25,000 visits per month. A peak occurs early in the year when the pollution is often at its worst.

We can compare this interest with the level of pollution as measured by the number of days in each month when the PM^{10} level exceeds 50ug on Brivibas street in the centre of Riga. This proxy is shown plotted under the website hits where it confirms that more site visits are coming when the pollution is worst.

It is not strong scientific evidence but is a good indicator that the service is being used. Unfortunately, there has not yet been a survey of users to understand the actions which may be taken.

A second major, but less obvious benefit is awareness raising and moving the issue of air quality up the political agenda. Whilst most people are aware that the air they breathe is polluted, few have a good understanding of the consequences and the links to their health. As we have seen with Ella, even health professionals are sometimes unaware of the fact that air pollution, like pollen and extreme weather, can trigger asthma attacks. Those at risk who suffer from existing, underlying health problems are more sensitised to the threat that air pollution can bring as they are exposed to the increased risk on a daily basis. However, for others this is less obvious and hence less urgent as a problem to be dealt with.

Even if the number of people affected is significant, the weight of their voices which can provoke action is limited.

airTEXT can help to address this problem by providing daily reminders of the air pollution that exists, but which may not always be seen. By raising awareness within the general population that air quality limits are reached or broken, this message also becomes more significant politically. Especially where children are affected, the views of the general public can be quite strong. Politicians are reacting to these messages meaning that one of the benefits of *airTEXT* is to place this message into public view and to provoke action as a result.

Further, *airTEXT* is a good news story in that it is helping to improve the quality of life for vulnerable citizens.

5.3.5 Other Beneficiaries

In Latvia, we found both the LEGMC and the Baltic Environment Forum using data coming from the *airTEXT* service as a means to support further research into health impacts.

As the government department responsible for environmental policies in the UK, Defra has taken a strong interest in *airTEXT*. Further investment of £700k has recently been granted to members of the *airTEXT* consortium to enable additional communication channels which are tailored to different communities including ethnic ones.

Other organisations are participating to research projects and in particular a project based in Newcastle which is planned to look at the links between health impacts and people behaviour to understand further the role that *airTEXT* and other warning systems can play.

5.4 Summary of Benefits

5.4.1 Economic Benefits

The economic benefits have been assessed at a large scale as accruing to society. Benefits in financial terms for each of the tiers have not been assessed.

In any case, firm figures are not easy to evaluate due to the difficulty of establishing a sound link between warnings / alerts provided by *airTEXT* and a reduction in the cost to society arising from poor air quality. We have taken two approaches as described in 5.2.

- The first is based on accepted figures for the welfare cost to a country or region. This uses well-established numbers for the welfare cost[3] but can only make broad assumptions for the impact of providing air quality alerts.
- The second takes a very direct approach by calculating how many hospital admissions can be saved by empowering individuals with the knowledge.

The figures are laid out in chapter 5.2 and lead us to conclude an economic benefit derived from the use of Sentinel data of €175k for Latvia, €3.8m for the UK, and €30m for Europe.

- Reduced societal welfare costs
- Savings through reduced hospital admissions

5.4.2 Socio-environmental Benefits

Even if the level of air pollution is an environmental parameter, the impacts on the environment are not well understood. That air pollution has an impact is well known but as expressed by the French commission referenced earlier[41], they have not been researched enough to be understood and quantified (ref 41, p84).

But, just as poor air quality affects humans, research has shown that it also affects mammals, birds and the ecosystem more broadly[62,63]. Mostly these are due to sulphur and nitrogen, but particles and ozone also cause damage. The resulting change of balance in the ecosystem is a direct threat to biodiversity. Measures taken to reduce air pollution levels for human health, have a secondary effect of improving conditions adverse to the ecosystem.

Understanding the levels and distribution, and hence sources, is critical. The CAMS model provides this critical information at a scale of around 10km which is augmented by the *airTEXT* service to provide more detailed information down to street level scale (about 10m). Whilst the model relies on many data sources, pattern of air pollution would not be possible without the data from the Sentinels.

Whilst this is only part of the picture, the information obtained through CAMs/*airTEXT* enables legislation for practices to reduce air pollution and is an indirect factor to introduce controls. *airTEXT* is judged to make a strong contribution to understanding the wider picture down to local scales and contributing to research into the impacts and has a limited indirect impact on reducing harmful emissions.

[62] UNECE, https://unece.org/air-pollution-ecosystems-and-biodiversity

[63] Effects of air pollution on ecosystems and biological diversity in the eastern United States

- Provides information to understand local and global causes of air pollution

5.4.3 Regulatory Benefits

Al though at the outset we had thought that the regulatory role would be small, we find that it plays quite a strong, albeit indirect, role. The alerts and even the forecasts do not in themselves support policy development. This is more the function of historical measurements which inform more precisely on anti-pollution measures.

But where *airTEXT* does play a role is at local level through the more detailed picture which emerges when it is used with the ADMS model. The latter allows measurements taken at large scale i.e. 1km or more, to be translated into the level of roads and some key infrastructure i.e schools, district heating centres etc. As such, data on air quality levels can be used directly or to inform where in-situ sensors should be placed to obtain a more precise picture.

airTEXT is used by the boroughs in London as a tool to support their Air Quality Action Plans and the Air Quality Status Reports produced each year. In this respect *airTEXT* is one of the tools used to help frame and monitor regulations at the local level.

The service is able to support local decision making linked to reducing pollution and to provide evidence to justify measures taken to the local population. Examples include regulation of cars and especially older diesel motors, suppressing installation of coal burning stoves in towns, introduction of “dust tickets” i.e. free passes for local transport when the level of pollution is high. Further measures discussed include controlling cars and lorries in sensitive roads i.e. where they pass by schools and car free days.

Overall, we consider that *airTEXT* makes a moderate contribution to regulation to control air pollution.

- Support assessment of policy impact at the local level
- Provide evidence to assess policy effectiveness and compliance and justify actions to the local population.

5.4.4 Innovation & Entrepreneurship Benefits

The ability to measure and specially to forecast air pollution levels is relatively new and, whilst this is possible through the use of local measuring stations, the results are not at a level to support individual decision making. This requires much denser measurement points which is made possible through the use of satellite data within the atmosphere models developed and used by ECMWF.

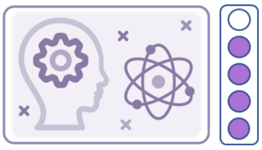
Hence the approach itself is innovative and as researchers and policy makers strive to improve both the quality and accuracy of measurements as well as communicating the risks to individuals, so innovative measures are sought.

- Stimulating innovative measures to communicate alerts to those at risk.

5.4.5 Science and Technology Advancement

Whilst the impact of air pollution on the population at large is quite well understood, at the detailed level our knowledge is poor. The use of *airTEXT* is intended to enable individuals to adapt their behaviour if they are vulnerable and if the pollution level is high. However, the impact of this on the health risk to an individual is poorly understood. A great deal of research is needed into the impact of air pollution at all levels on individual health. CAMS and *airTEXT* can provide wider scale views even down to a local level and can supplement the use of individual devices to measure exposure and almost certainly increase the scope whilst reducing the cost of the research.

Overall, the contribution to research is considered to be quite high.



- Supports R&D into avoidance behaviour and health consequences
- Support better understanding of local and global causes of air pollution.

5.4.6 Societal Benefits

Society as a whole is benefiting from the information on the levels of air pollution enabling individual citizens, especially vulnerable ones, to know when to avoid exposure at times of high pollution. As a result, this can avoid early deaths, improve citizens quality of life and more immediately, reduces emergency hospital admissions.

At the same time, the service is a tool to help local health professionals improve the service that they can offer their patients. It is suggested that this can lead to less and better use of medical treatments and to more efficient use of doctors' time as patients become more empowered. It can also improve planning of hospital admissions, taking account of forecast peaks in pollution.

The service also has a very important, although less visible benefit, of raising awareness. Making politicians more aware can lead to actions being taken. Making healthcare workers more aware can help them deliver better patient care. Making citizens more aware raises the likelihood of them pressurising the public bodies to provide better services.

In Riga, the introduction of Riga *airTEXT* has raised awareness of Copernicus and facilitated exchange between several different organisations not least at city and national levels. This support for the primary and secondary user to improve coordination and communication with the public is a positive effect that has been often identified within SeBS.

Overall, the societal impact is considered to be extremely high.

- Enables vulnerable people to manage risk, improving longevity and quality of life
- Supports local health practitioners and reduces hospital admissions.
- Raises political awareness of the importance of remedial actions.
- Encourage and support exchange between different stakeholders.

6 Conclusions

6.1 Summary of Findings

Based on the CAMS data supplied by ECMWF, the *airTEXT* service in Riga, in London and elsewhere is having a significant impact on the local citizens. By providing them with direct information on the level of air pollution, it is enabling individuals with a health risk to avoid exposure when the pollution is high. As a consequence, it is improving their quality of life, reducing the risk of premature death and reducing the emergency load on hospitals.

CAMS provides European-scale datasets with a resolution of around 10km on the ground. *airTEXT*, through the use of local models, enables pollution levels to be assessed to a much finer level, down to around 10m, which allows the pollution levels to be mapped and forecast down to street level. This is both more relevant and useful for individuals as well as for decision makers who are seeking to monitor the impact of regulations.

In Riga, the introduction of Riga *airTEXT* has raised awareness of Copernicus and facilitated exchange between several different organisations. Riga City Council has used findings from the service to help formulate its 5-year Air Quality Improvement Action Programme including a project considering to set specific policies for reducing emissions including to offer free public transports passes on days when the forecast level is high.

In London, the boroughs have joined together in the *airTEXT* consortium along with other leading stakeholders, which has enabled co-operation between them. As the service has been developed, some boroughs have managed to obtain funding to extend the service and improve the alert mechanisms.

The greatest benefit is for citizens who are vulnerable and who can adapt their behaviour when a high level of pollution is forecast. This reduces their risk of aggravating underlying conditions, reduces the risk of needing to seek emergency hospital treatment and improves their overall quality of life.

The administrative councils benefit by offering a better service to their citizens and hence fulfilling their public duties.

Society benefits through reduced mortality leading to longer working lives and reduced welfare costs which we have estimated as being a value of €350k for Latvia, €7.6m for the UK, and €52m for Europe. If the full welfare costs are considered, the benefits will be several times higher.

The benefits derived from the *airTEXT* service have been assessed against each of the 6 dimensions used in the SeBS methodology. **Figure** 6-1 below, shows the degree of benefit as we have assessed them for each of the dimensions.

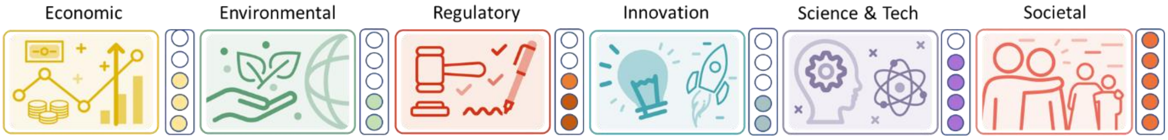


Figure 6-1: Summary of assessed benefits.

6.2 The Impact of Sentinel Data

How important is the Sentinel data for such a local service as AirText? The relationship is indeed complex and much looser than the one we found in other SeBS cases which is due to the deep dependency on the models used. As a result, Sentinel data is “buried” within the overall process and is difficult to trace to establish its relative contribution. Nevertheless, it is considered to be essential to the service and so the impact is high.

AirText is completely reliant on very detailed local-scale urban models in order to have an understanding and mapping of air flows and pollution emissions that is meaningful for citizens and local administrations. However, given the dynamics of the atmosphere even these local scale models need to take into account the dynamic boundary conditions that can be provided by larger scale models. Thus, the *airTEXT* service is derived from the Copernicus service for Atmospheric Monitoring (CAMS) delivered by the ECMWF.

Data from Sentinel satellites is one of many inputs into the ECMWF numerical model ie the Integrated Forecast System (IFS) which takes in data from many satellites, aircraft, ships, balloons, buoys and other platforms. We have seen that the dominant inputs are from Senetinel-5 (the TROPOMI instrument giving measurements of concentrations of NO2, O3, CO, SO2 CH4). These are operationally assimilated within the IFS and contribute to the improvement of its forecasts. Also, a special role is played by Sentinel-3 data that contribute to PM estimations from wildfires all over the world (CAMS global fire monitoring system). CAMS monitors the transport of emissions as well as the composition and can forecast the direction in which smoke will move. The CAMS daily forecast of Biomass Burning Aerosol Optical Depth - which is a measure of how much sunlight is able to pass through the atmosphere - indicates the amount of particulate matter in wildfire smoke plumes.

Furthermore, in the near future, a new Sentinel will be launched, Sentinel 4, which will sit in a geostationary orbit (all the other Sentinels so far have been in an inclined polar orbit). The main objective of the Sentinel-4 mission is to monitor key air quality trace gases and aerosols over Europe, in support of CAMS, at high spatial resolution and with a fast revisit time.

Hence, the impact of the Sentinel data is rather important in generating the air quality forecasts. One estimate places the satellite contribution today at around 10% of the benefit whilst, once Sentinel-4 data is being used, the increased frequency of observations will lead to a contribution of between 80% and 90%.

6.3 Widening the Perspective

Geographic Extension

We have examined the use of *airTEXT* in Riga and in London with the benefits extended to country level ie Latvia and the UK. In the economic benefits we have extended this further to consider that some €30m of economic benefit is generated at European level. We have not attempted to estimate beyond Europe to a global scale due to the inherent difficulty to align the underlying data i.e. pollution levels are much higher in many parts of the world. Nevertheless, the global benefits could be enormous.

Sentinel data and CAMS knows no geographical boundaries. But to provide useful information as described in this case, requires maps of air pollution to be generated down to 10m scale or even less. This enables the different pollution sources to be mapped as well as the complex air flows in cities which determines where the pollution is worst.

For this to be realised requires a great deal of further investment. Even if the data from CAMS is inherently global in nature, to realise the benefits of improved resolution from CAMS, the ADMS-Urban model needs to be configured for each city covered. This is not an insignificant task but a necessary one to have a strong influence on the health of individuals.

Technical Maturity

The benefits of the *airTEXT* service potentially can become greater as the underlying technology improves. This can lead to a better service which reaches a higher proportion of the population. In considering the future of the *airTEXT* service, evolution of the *airTEXT* element including the urban ADMS model as well as the CAMS must be taken into account.

The main evolution of *airTEXT* concerns the products which it will provide and the form in which these will be provided. Hence, a great deal of work is anticipated regarding the presentation of *airTEXT* results embedded in other specialist applications. This will enable the service to reach wider audiences and to serve a much larger part of society.

The major evolution of CAMS will be through the introduction of new data sources which will enable a more frequent update of more accurate products. The first Sentinel-4 satellite will be launched into geostationary orbit in 2024 and will provide hourly data on tropospheric constituents over Europe mainly for air quality applications. Sentinel-4 will continuously monitor key air quality trace gases and aerosols from geostationary orbit with Europe and North Africa in the field of view. Trace gases it will monitor include, nitrogen dioxide (NO2), ozone (O3), sulphur dioxide (SO2), formaldehyde, glyoxal, and aerosols which are vital for assessing air quality.

Increased User Uptake.

One key objective of ongoing development work on *airTEXT* is to provide the information in such a way that more people can have an easy access to it. Significant efforts and investments are being made to enable the *airTEXT* data to be shared with other services. One example we were given is for social networks around schools to be able to incorporate the data alongside other services for parents. Another is to provide the air quality information alongside London metro train times.

These efforts are aimed at increasing the user uptake and especially amongst those who are more vulnerable to poor air quality.

6.4 Final Thoughts

It is clear that air pollution and poor-quality air is a major, environmental problem for society. The links between air pollution and health are known but poorly understood. Much research is needed to help better understand these links and to design better protection for vulnerable citizens. This is even evident from the regular moves by the WHO towards stricter limits for acceptable levels of pollutants.

Providing information on air pollution levels helps society in many ways. Whilst some cost savings are welcome, of far greater importance is the impact it has on overall quality of life. Raising awareness of the degree of air pollution enables individuals to take life-enhancing decisions as well as informing health professionals to recommend better care for their patients.

As has been the case for meteorological forecasting, as this has developed with greater accuracy and precision of information, and as it has become ubiquitously available through mobile phones, so the utility has grown exponentially. People consult regularly on the expected weather over the next days to plan their activities on a personal and professional level. As information on air quality become similarly available, and as understanding of its impacts increase, so this data will also become of high value to society.

Further, it seems that there is no “safe” level of air pollution. Even at very low levels, some people are vulnerable. Just as this report is being finished, a newspaper reports on the results of a scientific study showing that air pollution can impact on mental health. There is a lot to be understood and information coming from CAMS and other services will provide valuable data for research.

In Riga and in London, levels of air pollution are relatively low compared to some regions, for example in much of Asia. Even so they exceed WHO guidelines and, on some days, by significant factors. The wide availability of information on air pollution levels, and alerts when thresholds are exceeded, is an extremely valuable service which governments can and should assure. Copernicus makes an essential contribution to these services.

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Annex 2: Glossary of Abbreviations

ADMS	Atmospheric Dispersion Modelling System
AI	Artificial Intelligence
AQM	Air Quality Monitoring
BEF	Baltic Environment Forum
C3S	Copernicus Climate Change Service
CAMS	Copernicus Atmosphere Monitoring Service
CERC	Cambridge Environmental Research Consultants
COMEAP	Committee on the Medical Effects of Air Pollution
DALY	Disability Adjusted Life Years
DAQI	Daily Air Quality Index
Defra	Department for Environment, Food and Rural Affairs.
ECMWF	European Centre for Medium-range Weather Forecasting
EEA	European Environment Agency
EFIS	European Fire Information Service
ELLE	Estonia, Latvia, Lithuania Environment
EPA	(US) Environmental Protection Agency
ESA	European Space Agency
GBD	Global Burden of Disease
GDP	Gross Domestic Product
GEMS	Global Environmental Monitoring System (for air)
GFAS	Global Fire Assimilation System
GLA	Greater London Authority
GMES	Global Monitoring for Environment and Security
IFS	Integrated Forecast System
IHME	Institute for Health Metrics and Evaluation
LEGMC	Latvian Environmental, Geology and Meteorology Centre
MAIA	Multi-Angle Imager for Aerosols
NASA	National Aeronautics and Space Administration
NIEHS	National Institute of Environmental Health Sciences
PHE	Public Health England
PMI	Particle Pollution
PROMOTE	PROtocol MOniToring for the GMES Service Element: Atmosphere
RACE	Rapid Action on Coronovirus and EO
SeBS	Sentinel Benefits Study
SLSTR	Sea and Land Surface Temperature Radiometer
UNEP	United Nations Environment Programme
WHO	World Health Organisation

Annex 3: General Approach and Methodology

This case has been analysed as a part of the Sentinel Benefits Study (SeBS), which looks at the value being created by the use of Sentinel data. It follows a methodology[5], established during a previous study, looking at a value chain for the use of a single EO service.

For each case, a value chain is established with a service provider and a primary user. The value-chain is validated with these two key players. Through a combination of desk and field research, we develop our understanding of all the actors in the value chain, the role that they play and how they may benefit through the use of the satellite-derived products.

The value-chain is divided into a number of tiers where the supplier is Tier 1, and the primary user is Tier 2. The last Tier is always "Citizens and Society". The number may vary according to the complexity of the value-chain. The benefits are then analysed against each of these tiers.

Once written, the draft report is then shared with all the persons with whom we have spoken, and their comments are incorporated, or a further discussion is held to establish a common understanding. Note that we are not asking these experts to endorse our findings but to indicate any gross errors or sensitivities which may have been introduced. At the end of this process, the report is made public.

As work has proceeded and more cases analysed, some modifications have been made to the methodology described in reference[5]. The first of these has been to expand from the two dimensions used earlier, namely economic and environmental benefits, to add those connected to societal, regulatory, innovation and entrepreneurship and scientific and technological. These six dimensions are described in the table A2-1 below.

Dimension	Definition
ECONOMIC	Impacts related to the production of goods or services, or impacts on monetary flow or volume, such as revenue, profit, capital and (indirectly, through turnover generation) employment.
ENVIRONMENTAL	Impacts related to the state and health of the environment, particularly as regards the ecosystem services on which human societies depend.
SOCIETAL	Impacts related to societal aspects such as increased trust in authorities, better public health or secured geostrategic position.
REGULATORY	Impacts linked to the development, enactment or enforcement of regulations, directives and other legal instruments by policymakers.
INNOVATION-ENTREPRENEURSHIP	Impacts linked to the development of new enterprise and/or the introduction of technological innovation into the market.
SCIENCE-TECHNOLOGY	Impacts linked to academic, scientific or technological research and development, the advancement of the state of knowledge in a particular domain.

Table A2-1: Definitions for the benefit dimensions

For each of these, a ranking has been introduced to give an immediate, visual impression of the scale of the benefits under each dimension. To aid in the quantification of these, a guide has been introduced which is shown in Table A2-2.

Rank	Benefit status	Criteria
0	**Null**	The case presents no perceivable benefits in this dimension, and no potential for such benefits to emerge is anticipated.
1	**Latent**	The value chain described in the case may, in general, present potential benefits in this dimension, but none have been identified or described in this particular instance.
2	**Manifest**: At least one benefit in this dimension has been identified through the value chain within the case. Its significance in the context of the case overall is judged to be:	**Low**
3		**Moderate**
4		**High**
5		**Exceptional**

Table A2-2: The ranking of the benefits.

In order to introduce further basis for comparison, a systematic approach has been developed for the analysis of the benefits. A series of indicators have been defined for each of the benefit dimensions against which each case can be considered.

The indicators used in the case are listed in section 5.3.6, and a full list of all indicators considered is provided in Table A2-3.

Dimension	Indicator	What it can mean.
Economic	Avoided costs (AV)	Alternative means to gather data
	Increased Revenues (IR)	Increased production/sales
	Reduced Inputs (RI)	Less time spent or material saved
	Improved Efficiency (IE)	Better use of resources
Environmental	Reduced pollution (RP)	Reduced amounts of pollutants in key resources e.g. water, air
	Reduced impact on natural resources (RR)	Reduced environmental impact e.g erosion, habitats/biodiversity.
Societal	Improved public health (IPH)	Less toxicological risk
	Common Understanding (CU)	Better control and communication of remedial efforts i.e through common maps.
	Increased trust and better transparency (ITT)	Improved preparedness / response
	Strategic Value (SV)	Common societal value to a country or region.
Regulatory	Improved policy / regulation design/drafting	Better information (scale, accuracy) leading to better regulation
	Improved efficiency in policy/regulation monitoring	Better information available to monitor adherence to regulations.
Innovation & Entrepreneurship	Innovative products	Sentinel data leads to creation of new products / services
	New Business models	New ways to generate income.
	New markets	Global nature of sentinel data enables international business development
	New businesses	Creation of new companies; start-ups
Science & technology	Academic output	
	Research exploitation	Applied science to operational services
	Research contribution	New product enabling scientific research

Table A2-3: Complete list of indicators considered within SeBS analyses.

Annex 4: About the Authors

Geoff Sawyer, BSc (Electronics), MBA

Geoff is the former Secretary General of EARSC having held senior management positions in the space industry and numerous representative positions in the UK and Europe. Geoff was the radar systems engineer responsible for the ERS-1 synthetic aperture radar and after many steps was, until 2011, EADS Vice President Corporate Strategist for Space. In addition to his extensive industrial experience, Geoff spent three years working for the European Commission where he was responsible for supporting the creation of the GMES initiative (now Copernicus). Geoff is now Strategic Advisor to EARSC.

geoff.sawyer@earsc.org.

Other Contributors to the Study:

Nikolay Khabarov, PhD

His expertise is mathematical modelling and optimization under uncertainty. Dr. Khabarov joined IIASA to strengthen the team in charge of quantifying benefits of improved Earth observations. Since then he has been a principal investigator and contributor to a range of research projects focusing on economics of adaptation, estimation of the value of information, disasters modelling, reduction of risks through innovative financial tools. khabarov@iiasa.ac.at

The SeBS Study Team

The SeBS study is conducted by a team of experts under the direction of ESA (the European Space Agency) and led by EARSC (the European Association of Remote Sensing Companies. The team is of a variable geometry and different experts work together on the different cases. The full team and the organisations for whom they work, is shown below.

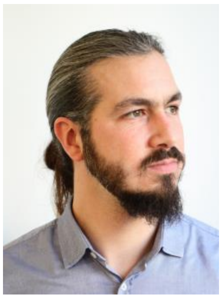
Geoff Sawyer, BSc (Electronics), MBA

Geoff is the former Secretary General of EARSC having held senior management positions in the space industry and numerous representative positions in the UK and Europe. Geoff was the radar systems engineer responsible for the ERS-1 synthetic aperture radar and after many steps was, until 2011, EADS Vice President Corporate Strategist for Space. In addition to his extensive industrial experience, Geoff spent three years working for the European Commission where he was responsible for supporting the creation of the GMES initiative (now Copernicus). Geoff is now Strategic Advisor to EARSC. geoff.sawyer@earsc.org.

Lefteris Mamais, MSc in Theoretical Physics

Lefteris is a strategy consultant with solid knowledge of programmatic, strategic and business aspects of EU Space Programmes (Copernicus and Galileo). In the past 10 years, Lefteris has been extensively involved in various studies and projects related to the development, market uptake and exploitation of EO downstream applications. He has been advising clients and partners across the full spectrum of the EO value chain, including EU institutions (EC, EEA, SatCen, ESA), universities and private companies.

lef@earsc.org and lefteris@evenflowconsulting.eu



Dimitrios Papadakis, M.Sc. Research Methods

Dimitrios is a strategy consultant and communication/dissemination expert with over ten years of experience in the commercialisation, uptake and exploitation of space-based data and applications, primarily as concerns the Copernicus programme and its services. He has provided expertise on a range of major market, cost-benefit and user uptake studies in the EO domain, for clients including the EC, ESA, EEA and the SatCen.

dimitri.papadakis@earsc.org and dimitri@evenflowconsulting.eu

Nikolay Khabarov, PhD

His expertise is mathematical modelling and optimization under uncertainty. Dr. Khabarov joined IIASA to strengthen the team in charge of quantifying benefits of improved Earth observations. Since then he has been a principal investigator and contributor to a range of research projects focusing on economics of adaptation, estimation of the value of information, disasters modelling, reduction of risks through innovative financial tools. khabarov@iiasa.ac.at

Christopher Oligschläger,

Christopher is an analyst with EARSC. He holds a Bachelor degree in European Studies from Maastricht University and a Double Master's degree in Governance and International Politics from Aston University, UK and Otto-Friedrich-University Bamberg. He gained first work experience (2017) at the Institute for European Politics in Berlin and the OSCE's Conflict Prevention Centre in Vienna before focusing on European space policy and concrete space applications through earth observation. christopher.oligschlaeger@earsc.org.

Dáire Boyle, BEng (Electrical Engineering), MSc Business & Economics

Dáire is a consultant with the Brussels-based consultancy Evenflow, who work in collaboration with EARSC on the Sentinel Benefits Study (SeBS). Dáire worked as an engineer for a large upstream oil & gas company in Aberdeen, Scotland for 4 years before moving to Belgium to complete a Masters in International Business Economics & Management. Daire has extensive root cause analysis and statistical analysis skills developed through both his professional and academic career. He currently acts as exploitation manager for the H2020 CYBELE project. daire@evenflowconsulting.eu