Blended REsearch on Air pollution using TecHnical and Educational solutions - CleanBREATHE

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Abstract. In this position paper we overview the CleanBREATHE project, its aims, goals and the proposed methodology. We review the problem of air pollution in the Balkan area, especially in N. Macedonia and the general problem of air pollution in the world. Then, we propose a methodology to increase awareness and increase the monitoring and control possibilities towards resolving the air pollution problem. We also present the research state and current gaps in air quality prediction and monitoring and present the project partners and supporters that, we believe, will leverage the results of this project and significantly improve the way people and decision makers perceive the air pollution data and the way that this data is leveraged towards resolving the air pollution problem in areas of concern.

Keywords: Air pollution, Education, Raising awareness, Air pollution prediction.

1 Introduction

Air pollution is a significant problem in the Balkan area and especially in N. Macedonia. The World Health Organization (WHO) Ambient Pollution Database for 2018 ranks Skopje as Europe's most polluted capital city regarding mean concentrations of PM 10 and PM 2.5 (UNEP, 2018). According to Dimovska & Mladenovska (2019, p.428), air pollution has a significant impact on the health and disease rate in N. Macedonia. Extreme air pollution and the resulting dramatically increased risk of airborne diseases reduce the attractiveness of the area as a center of life and work. The resulting scarcity of skilled workers and reduced investments are direct factors in a brain drain that impacts all academic and economic domains (Xue, Zhang & Zhao, 2019).

World Bank recommendations (2019, p.91) to strengthen air quality management in N. Macedonia include among others

- extending the monitoring network for air quality in order to present reliable information on pollutants
- reducing pollution from different sectors and
- strengthening public participation and support through public awareness and advocacy campaigns.

Mobile apps such as AirCare, initially known as MojVozduh, using open data from government and volunteer air quality sensors to map and visualize pollution in the Balkans (UNEP, 2018; Scott, 2018; Banovic, 2019) are of high relevance to both monitor air quality and pollution and visualize air quality to increase awareness in the general public. Active use since its launch 2014, (over 100,000 downloads on Android), and usage during high pollution months, show the interest by the general public for air quality data which lead to the "Plan for Clean Air" by the N. Macedonian Government.

Even though Germany complies with the Directive 2008/50/EC of the European Parliament and the Council (Air Quality) supplemented by Commission Directive (EU) 2015/1480 (Reference methods, data validation, and sampling points), WHO benchmarks are still exceeded, especially in big cities, indicating a need for action in Germany as well. Reverse trajectory calculations of polluted air masses show the relevance of air quality improvements in N. Macedonia for Germany.

Many air monitoring systems lack an appropriate interpretation and visualization of current and upcoming air pollution. They also fail to address the related (health) effects adequately and directly connect them to the individual. A sustainable solution calls for active citizen participation in the data collection process. However, besides monitoring and providing data, it is necessary to interpret and visualize the raw data sets and link them to users, respectively, give advice on behavioural changes. Finally, an informed public contributes to an improved environment.

The proposed project CleanBREATHE (Blended REsearch on Air pollution using TecHnical and Educational solutions) aims to make polluted air visible and initiate long term behavioral changes. Thus, our goals in lowering air pollution are:

- G1) Create citizen awareness and sustainable behavioural adjustment in two countries as a model for all of Europe, through a Critical Design Science Approach (Livari and Kuutti, 2017).
- G2) Design and plan sensor networks, new mobile sensing approaches and AI prediction algorithms.
- G3) Develop new business models aiming for environment-conscious behavior.

The following text is organized as follows: In Section 2 we give an overview of aims of the project and the used methodology. Then, in Section 3, we give overview of the state-of-the-art approaches in the literature and short analysis of the research gap that needs to be overcome. Next, in Section 4, we introduce the project partners and finally in Section 5, we give short conclusion.

2 Methodology

The aim of the CleanBREATHE Project is to research the impact of awareness-raising and (mobile) crowdsensing strategies to change the perception of air quality issues and investigate action by the general public, the industry, and government organizations. Expanding the air pollution sensor network through newly designed and engineered mobile and stationary sensors will allow us to collect more granular and locally relevant data on air pollutants. This will include geospatial and air-movement related data points on high-level polluters. Data visualization will be effectuated through

Pulse.Eco[1], a crowdsourcing platform that gathers and visualizes environmental data and the mobile app AirCare[2]. We will explore how an intuitive user interface and additional service increase the informational and educational value of web services and mobile solutions. Emphasis will be placed on actionable strategies by individuals to increase air quality and the impact of individual ownership of air quality measurement devices. Awareness of air quality parameters (AQI) needs to become a key element in public awareness of the environment like weather data with the significant difference that air quality can be changed through individual and community action.

CleanBREATHE seeks to improve existing approaches for the application of Machine Learning Algorithms based on feature extraction in air pollution prediction. Our new experiments investigating the combination of meteorological data and the air pollution measurement data using Convolutional Neural Networks look promising for applications like AirCare.

CleanBREATHE will use a partially existing infrastructure of sensors, data management, and air quality data to approach the awareness of air pollution. From a technical point of view, we will develop new concepts based on the existing AirCare app, its services, and its design. Moreover, through new mobile sensors, we use mobile crowdsensing (MCS) (Boubiche et al., 2019) to collect additional data with higher relevancy, and due to widespread distribution can rely on improved data availability. We then combine the technical perspective with an educational dimension and visualize the data in a way that app users learn and eventually change their behaviour. In this context, citizen awareness will also be increased through our critical design approach.

Following this, we will organize workshops for citizens and students to raise awareness on the topic and increase participation in the data collection process. Among local workshops, we plan to conduct joint workshops with students from Germany and N. Macedonia, using the perspective of young scientists to enhance the usability of the app and create further ideas for the research. Also, a direct transfer of knowledge about air pollution and solutions for companies will be discussed. This should lead to increased public awareness of environmental issues and, ultimately in reduced air pollution. In the next step, the results of the research will be presented to policymakers.

Finally, we aim to adjust marketable technological components and develop respectable pricing models for adaptable solutions like the Pollution Awareness App. In this context, we include our network of industry and SME partners, business innovators as well as citizens that contribute their specialist knowledge and experience to develop coherent business models, which will create new employment opportunities along with better living and working conditions.

To reach our goals mentioned above, we use a mixed-methods approach based on the Design Science Research Method (DSRM, fig. 1), including qualitative and quantitative social sciences methodologies. We mainly focus on data-driven action-oriented measures to improve air quality and knowledge exchange.

[1] https://skopje.pulse.eco/
[2] https://getaircare.com/

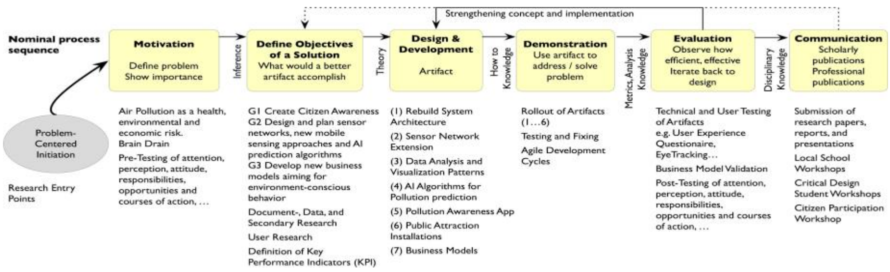

Fig. 1 CleanBREATHE Design Science Research Methodology Overview (based on Peffers et al., 2007)

Our research is motivated by the problem of air pollution and its connected risks described previously. The conception phase starts with a survey to test people's awareness and perception of the topic in the phase *Motivation*. After a literature review, we apply a User-Centered Design process (Vredenburg et al., 2002, p. 471 f.), conduct focus groups, expert interviews and define concrete indicators which we review again in the evaluation phase according to the defined research goals in the phase *Define Objectives*. With the collected data, material, and information, we will start the phase of *Design and Development*, working on the artifacts mentioned in fig. 1. In an iterative process, we will then test the artifacts and show how and in which context they are working (*Demonstration*). By validating our designs, adopting user tests, reviewing the indicators above, we will assess the overall project goals (*Evaluation*). Finally, we can distribute the research results and practical information to citizens (*Communication*). Referring to Livari and Kuutti (2017), we blend this DSRM with Critical Research traditions to achieve Human-Centered participatory design.

3 State of Science & Technology (research gaps)

Environmental studies cover a wide range of crowdsensing solutions for the monitoring of air quality. Recent research revealed that the integration of air pollution sensors in mobile and stationary applications, such as e-scooters, bicycles, but also mailboxes or pop sockets, has partially been taken up in the literature. Some studies have been using image-based crowdsensing through smartphones (Pan et al., 2017; Beltran et al., 2019). Other researchers have been focusing on wearable or integrated sensors (Outram et al., 2019; Eisenman et al., 2010). In a Taiwanese study on smart e-scooters for the elderly, Lin & Ye (2018) explore the potential of a Cloud Monitoring System collecting environmental data and integrating remote monitoring with sensor data transmission. An Italian study focuses on linking a crowdsensing platform for monitoring city air pollution with SmartBikes (Corno et al., 2017). Other studies found a solution to use smartphone applications to display air pollution to users (Liu et al., 2018; Marjanović et al., 2017). While the current literature covers a wide range of integration of sensors into devices, it does not expound on the visualization and representation of air pollution data to create awareness and, consequently, action.

Informal learning models through apps can educate citizens on a more sustainable lifestyle to inspire behavioral changes and stimulate more eco-friendly practices (Charitos et al., 2014). Intuitive and comprehensible data visualization of air quality is well suited to raise public awareness of air quality, create a personal connection, and encourage user participation. Diverse initiatives, mostly in a smart city context, tried to incentivize users through game-based approaches (McCallum et al., 2018; Wolff et al., 2016; Charitos et al., 2014). Social interaction as an element of mobile learning experiences and community communication (Charitos et al., 2014), as well as the easy access to comprehensive information and stimulating content, is essential for wide acceptance and good usability (McCallum et al., 2018).

Further research is required about vocational training and education in the field of crowdsensing-based data collection and air pollution measurements. The UNESCO roadmap for the implementation of the Global Action Programme on Education for Sustainable Development (ESD) (UNESCO, 2014) can serve as a first action point.

UN Sustainable Development Goals (SDG), SDG 3 (Good Health and Wellbeing), SDG 4 (Quality Education) and SDG 13 (Climate Action), especially “13.2 Integrate climate change measures into national policies, strategies and planning” and “13.3 Improve education, awareness-raising and human and institutional capacity on climate change mitigation, adaptation, impact reduction, and early warning”, are relevant for the project. (UN, 2020).

Legal requirements on accuracy and reference standards differentiate for large measuring stations that do not apply to small trackers. Under EU standards, PM10 and PM2.5 concentrations are averaged over 24 hours, according to DIN EN 12341:2014 rather than reported hourly. NO2 is reported on an hourly basis. In contrast, mobile air quality trackers provide real-time data, representing a snapshot not validated by standardized reference methods. This excludes trackers from collecting reference-quality data sets but allows them to play an active role in the identification of pollution sources and spatial analysis of a future placement of measuring stations.

The application of AI Algorithms in healthcare were investigated in a previous project (Zdravevski et al., 2017). Feature engineering and transformation of nominal features into numeric features also improves the prediction performance of AI algorithms (Zdravevski et al. 2015). We plan to increase the accuracy of air quality prediction based on corresponding meteorological prediction data and information about recent air pollution measurements by employing AI Algorithms such as deep learning algorithms to predict the air quality with high accuracy. The complex interdependency of meteorological and air quality data sets requires nonlinear modelling for which neural networks are an established approach (Gardner & Dorling, 1998). Recurrent neural networks differ from regular feedforward networks in the introduction of a time concept by feeding the output of a hidden layer back into itself. In basic recurrent neural networks, back-propagation gradients for maintaining long-distance connections tend to either vanish or accumulate and explode. LSTM networks address this problem due to their specific architecture, which causes dissipation of the sensitivity of older input data. In previous work (Arsov et al. 2020) we have shown that these algorithms can perform well in short term air pollution prediction and in (Arsov et al. 2021) we have evaluated their efficiency on multi horizon prediction compared to more traditional time series prediction models. In (Kalajdjieski et al.2020) we have evaluated the predictive performance of generative adversarial networks (GANs). The results of applying AI Algorithms on air pollution prediction are consistent with our previous experiments on smaller data samples (Stojov et al. 2018). When introducing geographically distributed data from many sensors with certain frequency, the usage of parallel computation becomes important. In our previous experiments we have leveraged parallel computation to improve algorithm speed performance (Zdravevski et al. 2015).

In our case the time series data samples are generated in near-constant time intervals. By classifying pattern recognition for similarities in data series, we will facilitate process automation of feature extraction, which can lead to a lightweight and robust model for air pollution detection. Our research aims to achieve a prediction model for air quality based on weather forecast information and current air pollution sensor data.

Our experimental model consists of a fully convolutional section consisting of temporal convolutional layers used as feature extractors, in pair with an LSTM section that processes the multivariate time-series input. The core idea behind the approach relies on its capability to learn how to deploy filters that are adept in detecting specific patterns.

Consequently, these filters can be used in forecasting future values in time series. Standard convolutional networks contain an activation layer, which is useful for transforming the input into a nonlinear value, which allows for learning more complex models. An interesting feature of these neural networks is that they are capable of processing raw sensor information while generating structured data that may contain the key domain-specific properties and can be used in the process of training the model. This approach allows the processing of multivariate data with limited time and computing power. Time-stamped data helps in data fusion of the weather and pollution data records and facilitates air quality prediction, provided that the weather forecast for the future period is known.

Convolutional Neural Networks are designed to map multi-dimensional data (in our case past air pollution, weather prediction) to an output variable (specific air pollution parameter). They generate an internal representation that allows the creation of the model that can scale variant structures of data. Long short-term memory (LSTM) is an artificial recurrent neural network architecture that is well-suited to classifying, processing, and making predictions based on time series data, even in a case of lags of unknown duration between important events in any of analyzed time series.

The availability of predictive relevant pollution data enables authorities to plan and enforce appropriate actions in a timely manner, such as controlling the impact of increased industrial production capacities and risk-profiles for outdoor activities. To increase the data availability, the outreach of the sensors must be very high and reliable. We have already researched the possibility of low-power, and low-cost data transfer protocols in our previous work (Dimitrievski et al. 2021).

4 Project Partners

In this chapter we give a short overview of the project partners and the main supporting parties of the project. The main partners of the project are The Magdeburg-Stendal University of Applied Sciences, The Ss. Cyril and Methodius University in Skopje, Faculty of Computer Science and Engineering. The project is also supported by Brody & Associates (Business Innovation Coach), the Business Accelerator UKIM, The State Office for Environmental Protection of Saxony-Anhalt (LAU), The State Ministry of Economy, Science and Digitalization, Science2Public, Fraunhofer Institute for Microstructure of Materials and Systems, Grünstreifen e.V., AirCare, Pulse eco and the O2 Coalition.

The Magdeburg-Stendal University of Applied Sciences is a public university of applied sciences located in Magdeburg, the capital city of Saxony-Anhalt and in Stendal. The university offers 50 study programmes at three faculties in Magdeburg and two faculties in Stendal. It enrolls around 3.700 students in Magdeburg and 1.800 in Stendal.

The Faculty of Computer Science and Engineering (FCSE) at the Ss. Cyril and Methodius University in Skopje is the largest and most prestigious faculty in the field of computer science and technologies in N. Macedonia, and among the largest faculties in that field in the region with a teaching staff of 60 professors and 20 associates and over 4000 active students.

Brody & Associates (Business Innovation Coach) - Florian Brody is an innovation moderator and certified business coach. Born in Vienna, he has been working in the Silicon Valley for over 25 years, where he co-founded five start-ups. He has extensive expertise in supporting companies and research projects in the integration of research and innovation processes and combining them with marketable business models and marketing strategies. He contributed to the CleanBREATHE proposal and supports the project in the conceptual phase.

Business Accelerator UKIM is a business technology accelerator that will help identify and support promising technology companies, start-ups, spin-offs and scale-ups in Macedonia. The measures include tailor-made early-stage investments and access to international markets, networks and communities. Our contact person is Aleksandar Stamboliev.

The State Office for Environmental Protection of Saxony-Anhalt (LAU) fulfils the legal obligation for air monitoring and provides information. It operates measuring stations at 24 representative locations in Saxony-Anhalt. By participating in our project, LAU hopes to be able to pre-validate suitable measuring stations with the help of crowdsensing-based information technology. Furthermore, a contribution to the evaluation of existing stations is expected. In addition, greater awareness of the activities and topics of the LÜSA (awareness raising) is desirable. On the other hand, the project partners hope to gain insights from the data and information of the LÜSA – Advice on technical questions of air monitoring and the provision of test facilities. Furthermore, the project consortium could participate in workshops and other exchange formats.

The State Ministry for Economy, Science and Digitalisation of Saxony-Anhalt supports CleanBREATHE’s efforts to strengthen the regional research strategy and to connect to international partners.

Science2public is a science communication agency that was leading the OpenLabNet Make Science! research project. The agency will support us through an extended network of partners and consult the project on all technical questions regarding the scientific communication and knowledge transfer.

Fraunhofer Institute for Microstructure of Materials and Systems (IMWS) could support the consortium in Citizen Science combined with aspects of air quality measurement. They have a wide range of experience from various projects like “OpenLabNet Make Science!”. The added value of the cooperation with the IMWS lies in the continuity of their own projects as well as in the contribution of the gained expertise.

Grünstreifen e.V. is an association that launched a citizen initiative measuring particulate matter in the city of Magdeburg (“Otto measures air quality”). The project consortium can benefit from this project in terms of Citizen Science and air quality measurement.

AirCare is a mobile app that uses open data from government and volunteer air quality sensors to map and visualize pollution in the Balkans (UNEP, 2018; Scott, 2018; Banovic, 2019). They will consult us on the development and implementation of technical issues and undertake joint research on infrastructures for digital supported learning.

Pulse eco is a crowdsourcing platform, which gathers and presents environmental data. The network of sensor installations and other third-party sources gathers the data and translates them into visual and easy to understand information about the pollution, humidity, temperature or noise in 15 cities in Balkan Region. They will mainly support our project in providing relevant data acquisition, presentation, and prediction, based on low-cost sensors for air pollution. Furthermore, they will provide insights in scaling sensor networks and possibility to use the sensor network platform for the detection of pollution sources.

O2 coalition is a civil initiative advocating for systemic and sustainable environmental solutions. The initiative will support workshops educating citizens and students on air pollution topics and connect the project to more civil society actors in N. Macedonia.

5 Discussion

As the project is in its early phase, we are currently working on the initial objectives and deliverables. Based on the initial results and the project progress, we believe that the project will significantly improve the public awareness and the policy makers decision process towards increasing the air quality in the region. By leveraging the state-of-the-art machine learning algorithms, improving the visualization and the interaction of the users with the available data and expanding the sensor networks availability and coverage, the state of the air quality monitoring and pollution detection and reduction will be significantly improved.

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