Real-Time Visual Analytics for Air Quality

Chiara Bachechi, Laura Po and Federico Desimoni

Abstract Raise collective awareness about the daily levels of humans exposure to toxic chemicals in the air is of great significance in motivating citizen to act and embrace a more sustainable life style. For this reason, Public Administrations are involved in effectively monitoring urban air quality with high-resolution and provide understandable visualization of the air quality conditions in their cities. Moreover, collecting data for a long period can help to estimate the impact of the policies adopted to reduce air pollutant concentration in the air. The easiest and most cost-effective way to monitor air quality is by employing low-cost sensors distributed in urban areas. These sensors generate a real-time data stream that needs elaboration to generate adequate visualizations. The TRAFAIR Air Quality dashboard proposed in this paper is a web application to inform citizens and decision-makers on the current, past, and future air quality conditions of three European cities: Modena, Santiago de Compostela, and Zaragoza. Air quality data are multidimensional observations update in real-time. Moreover, each observation has both space and a time reference. Interpolation techniques are employed to generate space-continuous visualizations that estimate the concentration of the pollutants where sensors are not available. The TRAFAIR project consists of a chain of simulation models that estimates the levels of NO and $NO2$ for up to 2 days. Furthermore, new future air quality scenarios evaluating the impact on air quality according to changes in urban traffic can be explored. All these processes generate heterogeneous data: coming from different sources, some continuous and others discrete in the space-time domain, some his-

Chiara Bachechi
“Enzo Ferrari" Engineering Department, University of Modena and Reggio Emilia, Italy e-mail: chiara.bachechi@unimore.it

Laura Po
“Enzo Ferrari" Engineering Department, University of Modena and Reggio Emilia, Italy e-mail: laura.po@unimore.it

Federico Desimoni
“Enzo Ferrari" Engineering Department, University of Modena and Reggio Emilia, Italy e-mail: federico.desimoni@unimore.it

torical and others in real-time. The dashboard provides a unique environment where all these data and the derived statistics can be observed and understood.

1 Introduction

The Word Health Organization (WHO) air quality guidelines updates [1] state that the reduction of air pollution levels can significantly decrease the burden of disease from heart disease, lung cancer, stroke, and both chronic and acute respiratory diseases (e.g. asthma). People already spend a lot of time deciding what to eat or drink to be healthy, they should also consider that the quality of the air they breathe strongly influences their health and lifestyle.

For this reason, public administrations and citizens need systems able to let them visualize the air pollutants concentration in order to change their behaviour and motivate the adoption of effective countermeasures. The TRAFAIR project[1] is a European project that aims to understand traffic flow in order to improve air quality. TRAFAIR monitors both urban air quality and road traffic in real-time and employs a chain of simulation models to predict urban air pollutant concentrations for the next two days. In the scope of the TRAFAIR project, a network of low-cost air quality sensors has been installed in 6 European cities: Modena, Florence, Livorno, Pisa, Santiago de Compostela, and Zaragoza. The measured pollutants are: CO, NO_2, NO, and O_3. These substances are recognized as toxic and the air is considered polluted if their concentration is higher than a legal limit for a certain period. Thus, to identify the level of pollution in a specific area the concentration of the pollutants should be monitored continuously and compared with the European standards.

This paper describes the TRAFAIR Air Quality dashboard implemented to share and visualize air quality data collected and generated during the TRAFAIR project. The dashboard is now employed by public administration members and citizens in the city of Modena, Zaragoza, and Santiago de Compostela.

Spatiotemporal data are difficult to visualize. Adequate visualization techniques are required to cope with data that have both spatial and temporal dimensions. Moreover, the majority of the available visualization needs to be frequently updated when new data are available. The dashboard communicates information about real-time, statistics, and trends of air quality conditions in a city through dynamic and/or interactive graphs and maps.

The dashboard was developed to manage a large amount of data coming in real-time from different sensors and characterized by both spatial and temporal dimensions. Moreover, it can handle complex data such as series of maps obtained from models or interpolation processes, and it is scalable and easily adaptable to different cities.

This work extends a previous work [2], where we mainly refer to the visualizations available in the city of Modena. In this version, the dashboard has been extended

[1] https://trafair.eu

to Zaragoza and Santiago de Compostela adapting some views and demonstrating the versatility of the proposed solution. The related work section has been enriched with some comparisons with similar web services. Section 3 has been extended and revise adding a description of the different types of geodata, outlining the chain of simulation models in the TRAFAIR project, and describing the characteristics of air quality monitoring sensors. Moreover, new visualizations have been described in Section 5: air quality forecasts, historical interpolation and forecasted maps, and future scenarios.

The rest of the paper is structured as follows. In Section 2, a literature review on air quality data visualization is provided and, Section 3 provides some background knowledge to better understand the air pollution monitoring system and the chain of models used to generate forecasts. In Section 4, the system architecture that enables the visualization is discussed. Then, in Section 5, dashboard properties, charts, and visualizations are presented.

Finally, the results displayed in the dashboard are commented and future works are described in Section 6.

2 Related work

Smart city data are generally communicated and shared with citizens and public administration members through dashboards. When dealing with air quality information, the main goal is to communicate where the hot spots are located. Air pollutants concentration data are difficult to interpret and their visual analytic can significantly influence the citizens' perception of the air quality. Visualizing gradually varied colour maps on Google Earth has a stronger expression than the original data table as proved for the city of BeiJing in [3]. In general, AQ maps provide an efficient way to investigate and understand the current status of air quality and to identify spatial-temporal patterns of air quality [4]. In [5], spatiotemporal data of weather and air quality have been compared with the incidence of COVID-19 in Spain to understand possible correlations. In [6], an interactive web-based geo-visual analytics platform allows the user to explore the results of the co-clustering analysis of their spatiotemporal data. Users can upload their data setting the co-clustering parameters and then the data are processed with a co-clustering algorithm considering both the spatial and the temporal dimensions of the dataset. Coordinated Multiple Views (CMV) are employed to display different aspects of the uploaded data: a geographical map, a linear timeline, a heatmap, and adjacent small multiples maps representing changes associated with timestamps. CMV is an efficient solution to help the user exploring spatiotemporal data.

City dashboards are analysed and compared in [7] with a focus on geo-visual analytics. The authors define the design principles for the communication of real-time time series. The main challenges of real-time are change-blindness and communication of spatiotemporal variability. When observing a map or a graph updated in real-time the user may not see the changes that occur if the changes are too fast or too

slow. Moreover, spatiotemporal data can vary in both dimensions and the user should have the possibility to observe the changes in both perspectives. In the development of the TRAFAIR dashboard, these challenges and the proposed principles have been taken into account.

Geospatial dashboards are classified as a web-based interactive interface supported by a platform combining: mapping, spatial analysis, and visualization. In [8], 3 types of dashboards are defined:

- Operational dashboards: that use indicators to provide descriptive measurements of smart cities,
- Analytical dashboards: that are based on data inferred from geospatial data using spatial analytic and are used as a diagnostic method for smart cities,
- Strategical dashboards: that can predict, estimate and visualize possible future outcomes.

The TRAFAIR Air Quality dashboard is a unique platform designed to be operational, analytical, and strategical in a unique solution.

2.1 Air quality applications

The urge to monitor air quality has become more pressing throughout the population that more and more platforms are being developed and made accessible. The most well-known are: AQICN[2], the platform of the World Air Quality Index project, a non-profit project started in 2007 to promote air pollution awareness for citizens and provide unified and worldwide air quality information, IQAir AirVisual Platform[3] a worldwide monitoring platform that brings together data collected by governments, companies, and individuals around the world; Air Portal[4] of the European Space Agency(ESA), a platform to collect, analyze, and display local air quality data that also combines satellite data, regional air quality forecasts, land use information, and local monitoring data to make accurate air quality predictions in urban environments; Airqoon[5]a hyperlocal air pollution management that performs visualization and mining of AQ, and designs action plans. Moreover, many companies that sell air quality sensors also developed and provided mobile or web applications for monitoring, like Plume Labs[6], AirCasting[7]. We compared the main features of those applications (as shown in Table 1) to identified the most common and used functions and visualizations.

[2] aqicn.org

[3] https://www.iqair.com

[4] https://air-portal.nl/

[5] https://www.airqoon.com/

[6] https://plumelabs.com/

[7] https://www.habitatmap.org/aircasting

Table 1 Features comparison among Air Quality applications [Legend:* the mobile version of those applications]

	AQICN	IQAir AirVisual	AIR-PORTAL	AIRQOON	PLUME LABS*	AIRVISUAL*
Gas monitoring	x		x		x	
PM monitoring	x	x	x	x	x	
AQI visualization	x	x	x		x	x
historical data	x	x	x			
AQ interactive maps		x	x	x		
AQ forecast		x	x	x	x	x
personalization option						x
critical activities					x	x

3 Background

This section provides basic information on what we mean for geospatial data and how air quality data are generated within the TRAFAIR project before being visualized through the dashboard. Firstly an introduction on the main aspects of geospatial and spatiotemporal data is provided. Then, the TRAFAIR project is described. Subsequently, the air quality sensors that have been used and deployed and the models and methodologies to create urban air quality maps are introduced.

3.1 Geospatial and Spatiotemporal Data

Geospatial data are information that refers to a precise position on earth. Spatial data are generally related to natural and man-made features whose size is between 1m and 10 km. The earth's surface is composed of different elements that can be represented as geometries or images. For this reason, there are two main types of geospatial data: vectors and rasters. Vectors are the geometrical representation of objects with a precise location on earth. The simpler geometry is a point associated with its coordinates in a given reference system, then there are lines (collection of points), polygons (collection of lines), multipoligon (collection of polygons), and other more complex geometries (e.g. collection of different geometries, triangulated irregular network, and polyhedral surfaces). Vectors represent the real world in a digital and deterministic manner: as a space populated by features each one with its geometry. For this reason, vectors are used to describe discrete geographic objects like ways, rivers, and buildings. Phenomenons affected by a geographical variation cannot be easily represented as vectors (vectorized). As described in [9], to represent variables that are continuous in space the study area is divided into smaller rectangles and the geographical variation can be represented by recording the local pattern of the variable over each rectangle. The resulting matrix of observations is called a raster data structure. More variables can be observed in the same rectangular area generating a raster composed of more layers (one for each variable) called 'bands'. Raster data are generally in modified images formats (e.g. GeoTIFFs, IMG, and JPEG

2000). Each rectangle is a 'cell' and is commonly referred to as a 'pixel'. Digital images, categories of land cover, weather conditions are typically stored as raster data. Mobile sensors and ubiquitous positioning devices have generated a new type of geospatial data: spatiotemporal data. Spatiotemporal data have both spatial and temporal dimensions. Both vector and raster data can have a temporal dimension. There are several different types of spatiotemporal data: geolocated time series, map associated with a timestamp, and trajectories. Measurements provided by a sensor installed at a certain location generate a geolocated time series: a sequence of values over time associated with a location on earth [10]. A geolocated time series has a fixed position in space and variations in the time dimension. Maps associated with a timestamp are data that cover a wide area of space and are associated with a fixed time instant. The time is fixed or aggregated and the variations are represented in the spatial dimension. The evolution of the observed phenomenon over time can be observed creating a collection of maps of subsequent instants. Finally, trajectories represent phenomena where both position and time change together, each timestamp is associated with a new position. Trajectories are used to represent the movement of objects (e.g vehicles, people, and particles). Mobile sensors generate trajectories of values, each measurement is associated with a time-position couple. In our use case, sensors can be moved around the city but they have a fixed position when collecting measurements. For this reason, we have not managed trajectory data. However, the information collected by each air quality sensor are geolocated time series and we generate a big amount of maps associated with a timestamp in the process of real-time and historical air quality monitoring.

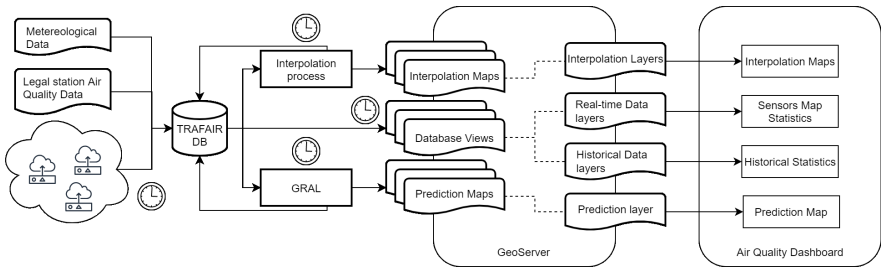

Fig. 1 The architecture of the TRAFAIR Air Quality Dashboard.

3.2 TRAFAIR

The Trafair project [8] [11] brings together 10 partners from two European countries (Italy and Spain) to develop innovative and sustainable services combining air quality,

[8] https://trafair.eu/

weather conditions, and traffic flows data to produce new information for the benefit of citizens and government decision-makers.

TRAFAIR raises awareness among citizens and public administrations about the air quality within an urban environment and the pollution caused by traffic. The project aims at monitoring air quality by using sensors in 6 cities and making air quality predictions thanks to simulation models. The two main goals of the project are:

1. monitoring urban air quality by using sensors in 6 European cities: Zaragoza (600,000 inhabitants), Florence (382,000), Modena (185,000), Livorno (160,000), Santiago de Compostela (95,000) and Pisa (90,000);
2. making urban air quality predictions thanks to simulation models based on the weather forecast and traffic flows (that are simulated thanks to traffic models [12]).

Monitoring air quality means setting up a network of low-cost sensors spread within the city [13] to monitor levels of pollutions in areas that are not covered by the legal air quality stations. Predicting urban air quality is possible thanks to a chain of simulation models. The traffic flows are simulated from the real measurements supplied by traffic sensors (as described in Section 3.2.1), then the emissions are calculated by taking into account the vehicle fleet in the city. Finally, the air quality predictions are calculated using an air pollution dispersion model (Section 3.2.2) taking into account the emissions, building shapes, and the weather forecasts.

3.2.1 Traffic model

Traffic models are promising tools that can simulate the movement of vehicles in the streets starting from different sources of traffic data. Two different traffic models have been employed in TRAFAIR:

1. SUMO (Simulation for Urban MObility) open-source simulation model.
2. The WiP traffic model developed by the Department of Information Engineering of the University of Florence [14].

SUMO[9] is a micro-simulation model for road traffic. In micro-simulation models, each vehicle is simulated as a singular entity with its direction, trip, and speed. SUMO can be configured in different ways to accept several data sources [15]. The WiP model instead is a macro-simulation model based on differential equations and physical constraints applied to a detailed street graph. A stochastic learning approach is adopted to estimate the road-sections capacities at each time slot of the day. In the city of Modena and Santiago de Compostela, induction loop detectors were installed under the surface of the street; this kind of traffic sensor can count vehicles that drive above them. Moreover, in the case of the city of Modena, they can also estimate the vehicle's average speed. Generally, these sensors collect an observation every minute. Otherwise, in Zaragoza only historical traffic data coming from mobile devices were available. In Modena (as described in [12]) and Zaragoza,

[9] https://sumo.dlr.de

the SUMO model was employed to perform daily simulations starting from the available traffic data. Then, the traffic of an average weekday of each month of the year was estimated considering historical simulations. While in Santiago de Compostela a similar approach was adopted employing the WiP model.

3.2.2 Emission Evaluation and Pollutant Dispersion model

Once the estimation of average traffic flow for each day of the week and month of the year have been generated, they are employed as a forecast for the traffic flow of tomorrow and the day after tomorrow. Then, considering the number of vehicles in each lane for each hour of the day the emissions are estimated through the VERT (Vehicular Emission from Road Traffic) model described in [16]. This emission model aims at estimating vehicular emissions basing its calculation on the latest emission factors suggested by the European Environmental Agency in 2018. VERT estimates NOx exhaust emissions and directly performing cold and hot emissions estimation from the number of vehicles simulated by a traffic model within a road network, in a specific time step. Finally, to predict the air quality conditions for the next 48 hours, we exploited the capabilities of the Graz Lagrangian Model (GRAL)[17], an open-source simulation software. The GRAL model simulates how the particles emitted by vehicles move in the air considering the weather conditions, the winds, and the shape of buildings. Moreover, additional emission sources (e.g. domestic heating) are included in the input data [18].

The GRAL model runs every day and, for each run, it generates 48 GeoTIFFs, one for each forecasted hour; each GeoTIFF represents the forecasted concentration of NOx in the urban area at a specific hour.

GRAL dispersion model was employed also to simulate in different seasons weekdays and holidays the effect on the air quality of a vehicle fleet composed differently (i.e. with more hybrid or electric vehicles). Emissions have been evaluated from the average weekday and holiday traffic flow of each season generating 24 different scenarios in each city (4 seasons, 2 day types, 3 vehicle fleets).

3.3 The Sensor Network

In the city of Modena, within the TRAFAIR project [11], 13 low-cost air quality sensors have been installed: 12 Decentlab Air Cubes, and one Libelium Smart Environment PRO. These sensors are connected to the municipality LoRaWAN network and send values of CO, NO_2, NO, and O_3 every 2 minutes. Similarly, in Zaragoza 10 Decentlab air cubes have been installed. In Santiago De Compostela 3

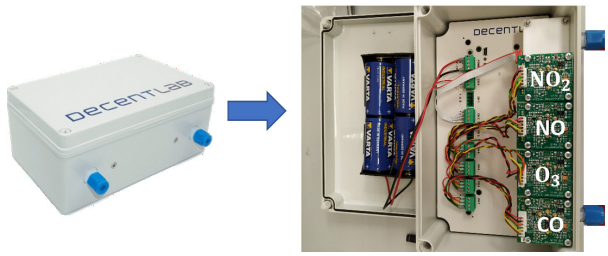

Fig. 2 An AQ device (on the left) and the inside content(on the right): 4 cells/sensors for measuring the level of 4 air pollutants (NO, NO_2, CO, and O_3 in this case).

Decentlab air cubes[10], 3 Libelium Smart Environment PRO[11], and a Kunak[12] sensor have been installed.

The low-cost devices are boxes with different sensors placed inside. Each sensor, also called 'cell', is devoted to the measurement of a specific pollutant. Figure 2 shows a Decentlab sensor[13] on the left and its interior view on the right. Inside the box, there is a sensor for air temperature and humidity, and 4 AQ sensors for NO, NO_2, CO, and O_3.

During their life cycle, the sensors are moved in different locations around the city; but, since the measurements of low-cost sensors are not highly accurate, they need to be periodically calibrated. The calibration phase is a period of the sensor's lifecycle that requires its collocation near an air quality legal station. The legal stations provide very accurate measurements about the concentration of pollutants in the air. In Modena, there are two legal stations managed by ARPAE, the environmental agency of the Emilia-Romagna region. One station is a background station located inside a green area, the other is a traffic station located near a highly congested road. In Zaragoza, there are eight air quality legal stations belonging to three different types: moderate traffic (3), intense traffic (3), background (2). In Santiago de Compostela, two ISO standard air quality stations are available, a background station and a traffic station, both managed by the local meteorological agency Meteogalicia. During the calibration process, machine learning algorithms (e.g. Random Forest, Support Vector Machines) or deep learning models (e.g. Multilayer perceptron, Long Short Term Memory) are employed to learn the association between the raw data measured by the sensor and the real concentrations registered by the legal station in the same location. Once the models are trained on the data collected during the calibration period, they can be employed to generate the calibrated value when the sensor is moved in a different location. Every 6 months, the calibration process is replicated to ensure the quality of the observations produced by the sensors. In this phase, the sensor is in the *calibration* status. Once calibrated, each sensor is able to provide

[10] https://www.decentlab.com/products/air-quality-station-no2-no-co-ox-for-lorawan

[11] https://www.libelium.com/iot-products/plug-sense/

[12] https://www.kunak.es/en/smart-environment/urban-air-quality/

[13] https://tinyurl.com/yunuaryt

a value of concentration for every pollutant. Once the calibration phase finishes, the sensors are moved from the legal station to different locations around the city. Within the scope of the project, some locations of interest have been selected. At this stage, the sensor is in the *running* status and the collected data are accurate enough to be used for the estimation of air pollution. The sensors provide raw milliVolt measurements for each pollutant every 2 minutes. Those values are stored in the project database and are converted in micrograms (milligrams for the CO) per cubic centimeter every 10 minutes interval. The concentration values are stored in the project database too for further trends and statistical analysis.

3.4 Air Quality Maps

Public administrators need to know the position and status of the installed sensors, monitor real-time air quality conditions, visualize statistics concerning the air quality conditions in the urban area, and quickly identify if there are hot spots, i.e. areas with a high concentration of pollutants. Each air quality sensor provides the four pollutants concentrations in the location where it is placed and, by spatially interpolating the values of all the sensors, it is possible to estimate the pollutant concentration in the whole urban area. Thus, an R script was implemented to produce GeoTIFF files interpolating the pointwise concentrations using Inverse Distance Weighted(IDW). As described in [19], IDW is a deterministic (non-geostatistical) estimation method where values at unmeasured points are determined by a linear combination of values at nearby measured points. Value at location $x*$ is evaluated as:

$$x^* = \frac{w_1 X_1 + w_2 X_2 + \ldots + w_n X_n}{w_1 + w_2 + \ldots + w_n}$$

where $x*$ is the value to predict and w_i is the weight of the sampled point X_i. Weights are evaluated as the inverse of the distance between the location to predict and the sampled data point i to the power of p:

$$w_i = \frac{1}{d^p_{i-x^*}}$$

The rate at which the weights decrease is dependent on the value of p. As p increases, the weights for distant points decrease rapidly. If the value of p is very high, only the immediate surrounding points will influence the prediction. In our use case, we employ $p = 2$. Other interpolation techniques such as IDW with p equal to 1, nearest neighbourhood, ordinary Kriging, and thin plate spline, have been considered and tested. Both IDW and Nearest Neighbourhood provided good performances. We chose to use IDW and to produce a new map every time new calibrated values are available i.e. every 10 minutes.

In order to present the air pollutant concentrations to diverse audiences, we decide to share numeric data and to display them using three colour scales: the one used

by the ARPAE in Modena, a customized colour scale named TRAFAIR in Zaragoza and Santiago de Compostela, and the one proposed by the European Environmental Agency (EEA) for all the cities.

4 Architecture and Technologies

The main purpose of the TRAFAIR dashboard was to support the public administration in decision-making activities. Public administration members were involved in the deployment of the dashboard and contribute to defining the requirements:

R0 automatically updating visualization of real-time measurements of low-cost sensors in the city,
R1 visualization of sensor positions and their status,
R2 statistical information about historical measurements;
R3 visualization of the average day of the week trends and other aggregations in space and time;
R4 visualization of the current concentration of pollutants in the city area updated every 10 minutes;
R5 comparison between the different points of observation;
R6 visualization of the forecast of NOx concentration in the whole city for today and tomorrow;
R7 visualization and download of historical forecasting maps;
R8 visualization of historical maps based on the daily average concentration measured by low-cost sensors;
R9 comparison between the NOx concentration generated by different scenarios;

Moreover, since the number of urban sensors is destined to increase scalability must be ensured. Scalability is the ability to add or remove sensor devices without affecting the system's availability. Figure 1 illustrates the architecture of the dashboard. The data are stored in the TRAFAIR DB. The information contained in the database is exposed through GeoServer over the Internet and used by the TRAFAIR Air Quality dashboard.

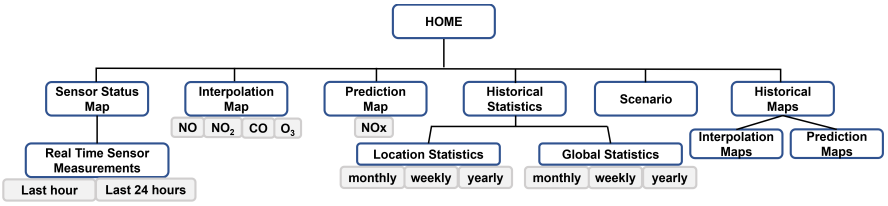

Fig. 3 Site Map of the TRAFAIR Air Quality Dashboard.

4.1 TRAFAIR Database

The TRAFAIR architecture relies on a PostgreSQL database. For efficient management of time series and spatial data, the database has been equipped with PostGIS and timescale extensions. The spatial extension ensures the correct management of both vector data (e.g the position of sensors) and raster data (e.g interpolation maps). Its main role is the collection of the stream of data generated by the low-cost air quality sensors. In order to preserve the complete history of the measurements, the database contains basic information about the sensors themselves. Then, every time the sensors are moved, new data related to their current positions and status are inserted. Each sensor has its own life-cycle and for every instant in time the physical sensor is associated with a postion in space and one of the following status: $running$, $calibration$, $broken$, and $offline$. When the sensor is collecting data it is in the $running$ status; While, when it is collecting data but it is located near a legal station for the calibration process its status is $calibration$; Otherwise, when the sensor is not able to collect data or the collected data are not reliable the sensor is in the $offline$ or $broken$ status.

Each sensor measures pollutants concentrations and sends data packages every 2 minutes. The data are sent over a LoRaWAN network and are captured by different gateways. Once the gateway receives a data package, it redirects the data to the TRAFAIR database. In particular, the sensors are able to capture the concentrations of CO, NO_2, NO, and O_3, humidity, and temperature and send to the database the intensity of the voltage generated during the analysis. Therefore, for each observation captured by the sensor, we store the measured voltages of each gas (in millivolts), the temperature, the humidity, and the battery voltage. As indicated in Section 3, each sensor needs to be calibrated to collect reliable data. Alongside the measurement of our sensors, we collect the air quality data generated by the legal air quality stations and run a calibration algorithm to associate the measured voltages to the air quality data collected from the legal station. The parameters of the calibration algorithm and the data used during this calibration phase are also kept in the DB. Once the calibration step is completed, the data incoming from the sensors, are converted from millivolts to concentration (milligrams for cubic meter) and then stored in the database.

Beside the main schema containing the core data, the database contains other schemas. In order to store the view that have been generated for the creation of visualizations in the dashboard, we created the $webapp$ schema. While, the $open_data$ schema was created to store the data that are published as open data, and the $mobile$ schema for the visualizations of the mobile apps.

4.2 GeoServer

To share geospatial data in an easy and open soruce solution, GeoServer GeoServer[14] [20] offers a platform that allows to upload and publish several types of data soruces. GeoServer accepts group of files or single files in raster or vector format, tables hosted by a PosgreSQL database, and even images. For each data source a store is generated. Then, from each store, different layers can be created. Layers enables the handling of temporal and spatial data using standard OGC protocols:

1. the WFS (Web Feature Service),
2. the WCS (Web Coverage Service),
3. the WMS (Web Map Service).

The WFS standard allow exposing spatial and temporal data as GML, KML, JSON, CSV, XML, and other data formats; This protocol was exploited to expose the data for drawing the graphics presented in Section 4.3. The WCS standard manage "coverages". A "coverage" refers to objects covering a geographical area like a set of points, a regular grid of points, or a set of segmented curves. Finally, the WMS standard is employed for generating server-side maps that are sent to the client as regular images or gif files. This solution is adopted to avoid sending fine-grained data to the client; The interpolation maps described in Section 5.4 and the prediction maps generated by the air pollution dispersion model described in Section 5.5 have been exposes through the WMS. Moreover, the choice to deploy an instance of GeoServer to share the data was motivated by the need of a higher security level. GeoServer allows separating the access to the database from the access to the generated visualizations. Furthermore, GeoServer helps to easily manage the publication of spatial and temporal data. Another important reason that motivate the adoption of GeoServer was the need of a common platform with the same structure. Since the data structure deployed in the 3 cities is slightly different, to manage this heterogeneity of data the same layers were generated in GeoServer. Moreover, GeoServer we exploited the GeoServer's ImageMosaic plugin that allows the creation of a mosaic from a set of GeoTIFFs (georeferenced rasters).

The mosaic is a set of geospatially rectified images releted spatially or temporally to each otehr.For example, an ImageMosaic data store was generated to group the GeoTIFFs prediction map of several time slots into a unique element. In the ImageMosaic data store the images can be associated to a timesamp allowing to investigate the evolution over time of the represented phenomenon. This solution is suitable for the maps associated with a timestamp described in Section 3.1. Furthermore, other services like WPS (Web Processing Service) or WMTS (Web Map Tile Service), and other plugins can be integrated into GeoServer if needed.

Since TRAFAIR project requires the generation of several maps and visualizations that need to be updated frequently we exploited the GeoServer API system to automatically generate the layers required for exposing the database views. A de-

[14] http://geoserver.org/

tailed description of the ingestion of layers in GeoServer and the publication through OGC services of air quality open data is depicted in [21].

For handling sensor observations, status and positions, and statistical data about sensors or locations, 9 views in the web app schema and 9 layers in GeoServer have been created. These layers consist of 3 Real-time Data layers and 6 Historical Data layers as shown in Figure 1. A dashboard requires a quick response time; thus, some views have been materialized. As a result, the average response time decreases from 10 to 0,7 seconds. The map layers are different and requires some additional explaination about the structure of the file and the process that generates it. The interpolation map layers are collections of the GeoTIFFs file created by the interpolation process. These raster files are unique but are composed of 4 bands, one for each pollutant. Each layer is associated with one of the band and with a defined style to visualize the concentrations of a pollutant as a coloured map.The prediction map layer and the layers of the scenarios are created exploiting the ImageMosaic plugin to merge the 48 GeoTIFFs generated by GRAL into an ImageMosaic data store. One layer is generated for each forecasts and each possible scenario.

The content of the Historical data layers and Prediction layer is updated daily; moreover, the Interpolation layers and real-time data layers are refreshed every 10 minutes.

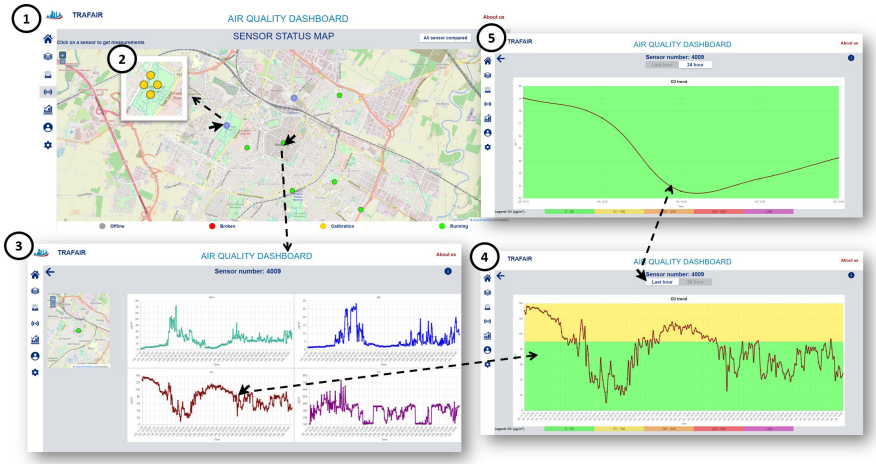

Fig. 4 Views accessible from the sensor map view: (1). A sensor cluster when clicked is converted into several single clickable sensors (2). Clicking a sensor the last 24 hours measurements for the four pollutants are visualized (3). Zoomed view of a single graph with colour scale indicating the level of pollutant concentration.

4.3 Dashboard

The dashboard is a web application based on Angular 7 design framework described in [22] and writted in Typescript language. Two different libraries are employed for the graph visualization: D3 [23] and Chartjs [24]. Instead, in order to create maps, Open Layer [15] library is used. The TRAFAIR dashboard is a single-page client applications, Angular was chosen for its implementation due to its modular structure that allows the reuse of code. The Angular framework is based the NgModules i.e. building blocks of related codes. NgModules offers the compilation context for 'components'. In Angular, a component is a collection of related screen elements that compose a single view.

Besides, 'services' provides the functionalities that are shared between different components. They are also employed to share information and data between components. In our implementation, each view has its corresponding component. Component can be in a parent child relationship when the child component is a part of the parent component, in this case we have a single view represented by the parent component and the child component inside it. Parent and child components can share data through the '@input' decorator, without using services. We employ child components in some views where graphs change accordingly to some option selected by the user in a form defined in the parent component.

Moreover, several services have been defined to share information between components that are not in a parent-child relationship. Services support both the retrieval and the modification of the information.

The main services implemented in TRAFAIR Air Quality dashboard, as shown in Figure 1, are:

- the authentication service: to share and modify data concerning the user session.
- the city selection service: to share and modify data about the selected city (our web application supports three cities)
- the language selection service: to share and modify data about the selected language (our web application supports three languages)
- the GeoServer service: to define functionalities related to interrogations to obtain data using the GeoServer API.
- the threshold service: to share and modify the selected colour scale thresholds used to generate graphics and maps colours.

5 TRAFAIR Air Quality Dashboard

Within the TRAFAIR project described in Section 3.2, a suite of monitoring tools for public administration was realized.

[15] https://openlayers.org/

The TRAFAIR Air Quality Dashboard[16] [2] allows them to visualize air quality conditions in the cities. Another dashboard was realized, SenseBoard [25] an environmental expert-oriented dashboard for monitoring the status of the sensors and the calibration. These two dashboards have different purposes. SenseBoard is for technical experts; however, the TRAFAIR Air Quality dashboard is created for a non-expert user that needs to monitor quickly transitioning data. The dashboard enables the analysis and the estimation of the diffusion of pollutants in the urban area of all three cities. The user can get an overview of the air quality conditions in the cities: tracking and comparing over time and space pollutants concentration, viewing the real-time air quality condition here-and-now. Time series and geospatial data are displayed through interactive graphs and maps. The graphics are dynamically updated when new data are released. The user can interact with several visualizations selecting, filtering, and querying data, zooming in/out, panning, and overlaying. Since the dashboard was initially conceived for public administrations to help them in decision making, not all the visualized data are public and can be visualized by a not-logged user. Administration members should log in to access this private data. City maps are obtained from Open Street Map (OSM)[17], the data visualized and the map layers are generated querying GeoServer configured layers.

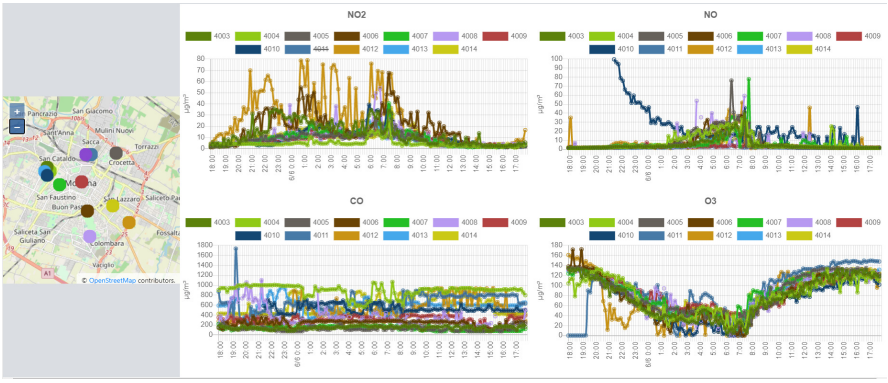

Fig. 5 The view that allows comparing the last 24 hours measurements of the four pollutants concentration of all the available sensors.

In order to respect the principles introduced for the visualization of real-time data in [7], the user needs a time reference to easily gasps changes in the visualization. For this reason, timers inserted inside the Typescript code of the web application views are updated with the same frequency. When the timer expires a new request is sent to the GeoServer layer and then the view is updated, and the timer is restarted. A label in the view advises the user about the time stamp the visualization refers to. The colours significantly help to convey the criticality of air quality conditions

[16] The dashboard is available online at https://trafair.eu/airquality.

[17] https://www.openstreetmap.org/

and the definition and choice of the colour scale can influence the perception of the user. The functionalities related to the colour scale are described in Section 5.1. As can be seen in Figure 3, the site map is composed of 6 branches: the sensor status map (Section 5.2), the interpolation maps (described in Section 5.4), the prediction map (described in Section 5.5, the historical statistics (described in Section 5.3, the Scenario view (described in Section 5.6), and the historical maps (described in Section 5.7).

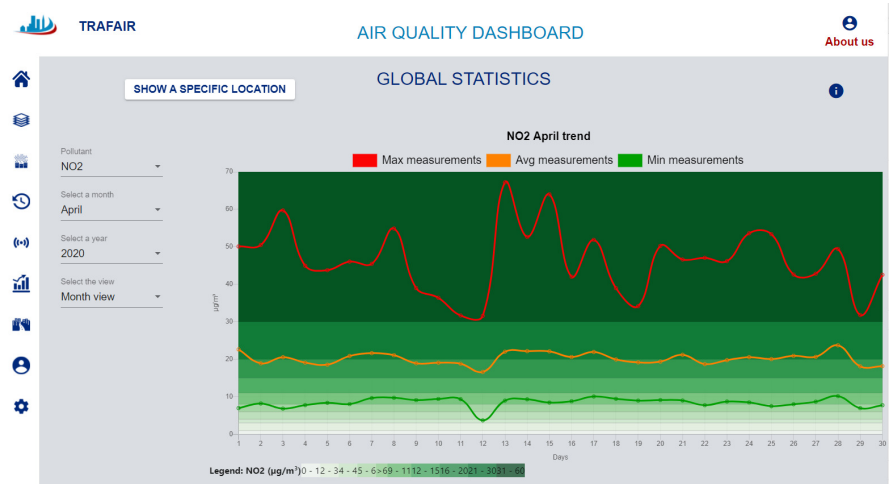

Fig. 6 NO_2 concentration trend for the whole urban area of Zaragoza in April 2020. The background colours are based on the TRAFAIR scale.

5.1 Colour Scale

Environmental experts involved in the TRAFAIR project decide to adopt the EEA colour scale. This colour scale was defined by the European Environmental Agency[18] that defines the threshold and the colours for each pollutant. Moreover, in Modena, a different colour scale was defined and used by the ARPAE agency. The environmental experts' team also define a new colour scale that helps to visualize better small changes in pollutants concentration. This colour scale was defined for the cities of Santiago de Compostela and Zaragoza. Thus, the user can choose between ARPAE or EEA colour scale in Modena and TRAFAIR or EEA colour scale in the other two cities. In the TRAFIAR Air Quality dashboard, the setting-up page (Figure 7) allows the user to choose between the available colour scales for the selected city. Once the

[18] https://www.eea.europa.eu/

user chooses a colour scale, the Threshold service will provide this information to all the views in the application.

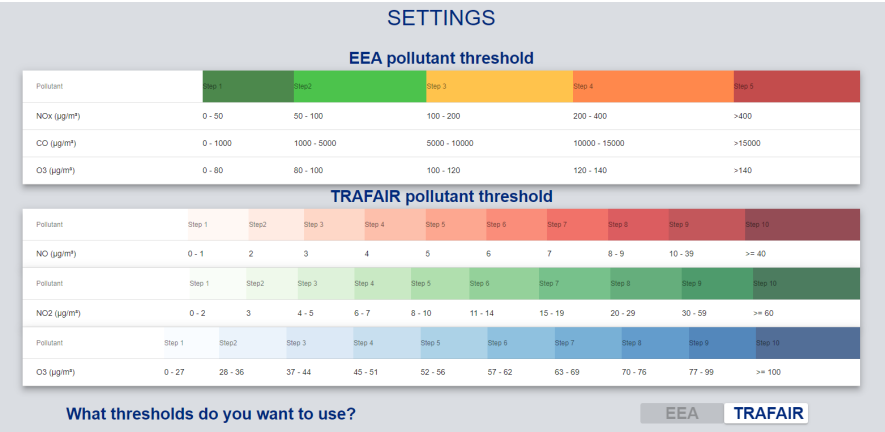

Fig. 7 the settings page of the dashboard where the user can select the colour scale.

5.2 Sensor Status and Real-time Measurements

This branch of the TRAFAIR Air Quality dashboard displays the measurements of low-cost air quality sensors and their position and status. To satisfy the requirement **R1** introduced in section 4, the 'sensor map' view shows the position of each sensor and its status(see Figure 4-1). The status of the sensor is represented through the colour of its marker on the map. Besides, the sensor position is obtained from the TRAFAIR database and saved in the GeoServer instance as a layer queried with the WFS standard. During the calibration phase, sensors are placed near the legal station and it may happen that several sensors are in the same position. When sensors are placed in the same location, to allow the correct visualization of all the sensors, the map initially shows a big spot displaying the number of sensors located in the specific position. Then, the user can click on the big spot to see the status of every single sensor separately (see Figure 4-2). To obtain this visualization we modified the Open Layer library adding some additional functions to manage clusters of sensors.

To satisfy requirement **R0**, by clicking on the marker of a sensor in the map the user can open a new view that displays the last 24 hours measurements of the 4 pollutants of the selected sensor (see Figure 4-3).

The time series of sensor measurements is associated with a position on earth (the position of the sensor); thus, it is a geolocated time series (Section 3.1). To display a time series of observations with a frequency of 10 minutes in a linear representation a great display space is required in order to produce a comprehensible

visualization. Therefore, if the user wants to see more clearly the values of a specific pollutant by clicking on the corresponding graph a zoomed visualization will appear. In this zoomed visualization, the background of the graph is coloured accordingly with the selected colour scale (ARPAE or TRAFAIR and EEA). The user can select the colour scale on the setting-up page of the dashboard. The legend behind the graph describes the meaning of the colours and helps the user to identify values that are critical and may require his attention. Public administration members give us feedbacks about this visualization underlining the need for a view that allows them to easily compare the measurement of different sensors located in different points of the city. Therefore, an additional view was created to satisfy their requirement. By clicking on the 'all sensor compared' button in the top-right of the sensor status map, a new page is opened where the sensors' time series are overlaid in a single chart, one for each pollutant. In this way, the last 24 hours measurements of the sensors can be compared; Moreover, since the view contains a map with the position of each sensor (see Figure 5), the areas of the city with the highest pollutant concentrations can be easily identified. In order to associate to each curve the correct position, the colour of the curve is the same as the sensor marker in the map. These graphs are interactive, by clicking on the label of a sensor the user can remove its measurements and decide the set of sensors that he wants to compare. The contemporary use of maps and charts allows visualizing the geolocated time series together with their location, combining the spatial and the temporal dimensions in a single visualization.

Every 10 minutes, the graphics are automatically refreshed.

5.3 Historical Statistics

The requirements **R2** and **R3** underlines the necessity of a statistical overview of historical data. During the TRAFAIR project, all the collected data are stored in the TRAFAIR database and uploaded in GeoServer. A longitudinal archive of data is generated. Historical data can be examined over different time frames, such as a week, month, and year. Moreover, archival data are used to detect trends and provide contextual information for a better understanding of current data. The view is composed of several drop-down menu windows that allow defining the year, the month, the day, and the time aggregation. The user can interact with the view changing the set-up to visualize different graphs. Moreover, two different types of statistics are provided: global statistics, and location statistics. Global statistics are evaluated on the whole urban area considering all the available sensors observations. They provide an overview of the air quality conditions in the city. Location statistics are accessible through the button 'show a specific location' in the top left of the global statistics view. A map that shows all the available locations to select will appear and by clicking on the location marker the user can visualize the selected location statistics. Location statistics are evaluated individually for each location where sensors have been placed during the project. Since sensors are moved around the city, they can be placed in the same position simultaneously or in different

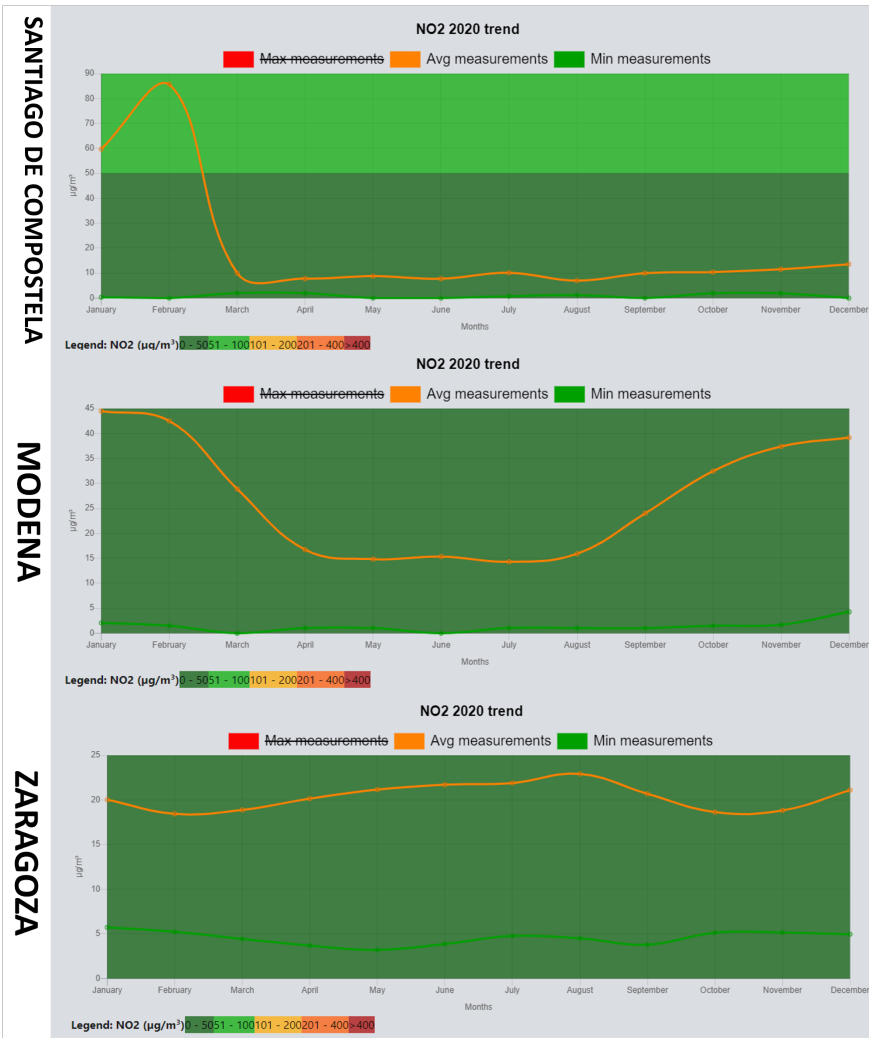

Fig. 8 The three year views of NO_2 concentration in 2020 for the cities of Santiago de Compostela, Modena, and Zaragoza.

periods. However, the measured pollutant concentration does not depend on the physical sensor but strongly depends on the location. Thus, the location statistics are evaluated considering all the observations registered in the selected period by all the sensors that were placed in that location. The global and location statistics views are very similar, the main difference is that in the location statistics view the name of the location is at the top of the view. Three different graphics are provided: the month graph, the year graph, and the week graph.

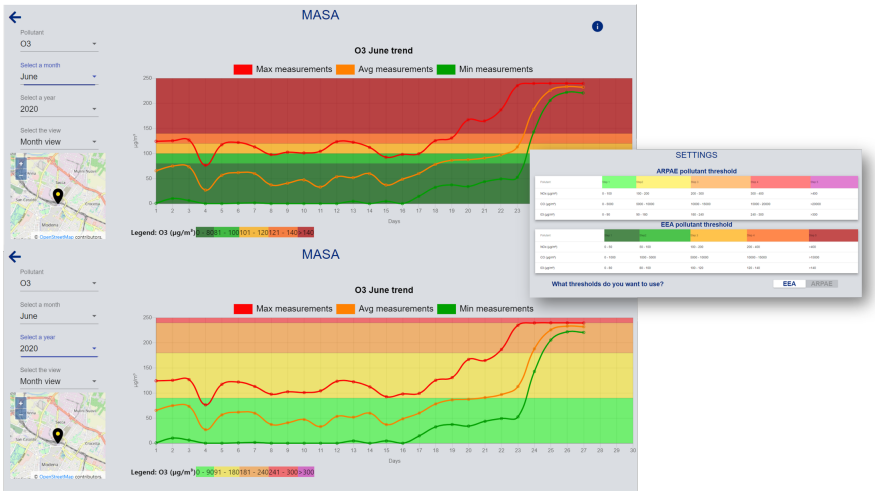

Fig. 9 Two month views for $O3$ in June 2020 in the city of Modena: the top view uses ARPAE scale and the lower EEA scale. The figure shows also the settings page where scales can be modified.

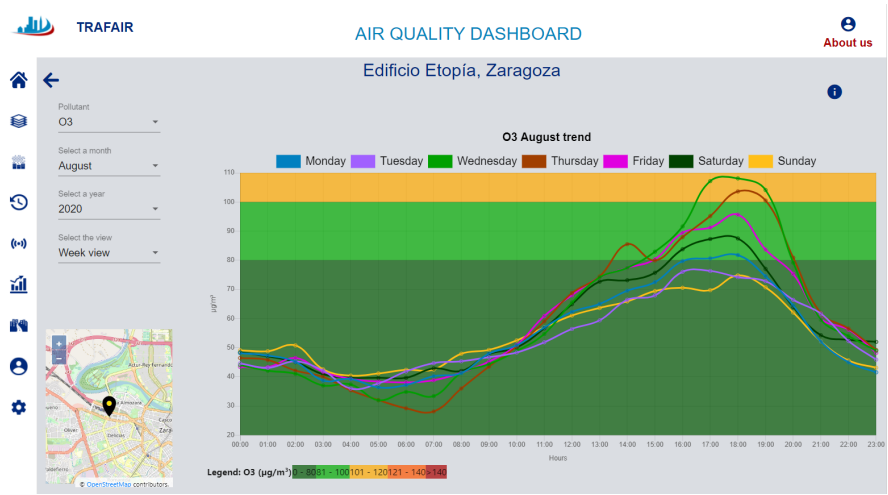

Fig. 10 The average weekdays view for O_3 in August 2020 in Edificio Etiopìa, Zaragoza. The colours of the background are based on the EEA scale.

The month graph is available for each month of each year. Once selected the month, the year, and the pollutant from the drop-down menu windows, a graph that shows the maximum, minimum, and average time series of values of pollutant concentration measured in every day of the selected month is generated. The user by clicking on the name of the curve can remove it from the chart. The background colours indicate the level of concentration of the pollutant accordingly to the selected colour scale.

Figure 6 display the global month view of NO_2 for April 2020 in the city of Zaragoza. The selected colour scale is the TRAFAIR colour scale and maximum values are in the higher colour class.

Figure 9 shows the same graph in the same location displaying the monthly trend of $O3$ in June 2020 in the city of Modena but with two different scales. As can be seen, the adoption of a different colour scale can significantly influence the perception of the user. The visualization on the top adopts the EEA scale and gives the impression of very high and dangerous values of concentration at the end of the month. The visualization with ARAPE scale instead associates an orange colour to these values giving the impression of less severe air quality conditions.

For each year in which the data are available, the user can select the year and the pollutant, and then the visualized year graph shows the time series obtained from maximum, minimum, and average values of the selected pollutant concentrations measured for every month of the selected year. The maximum, minimum, and average curves can be removed to ensure a better visualization, and the background is coloured according to the selected colour scale. For example, in Figure 5, the three cities' year views for the NO_2 concentration are displayed. The selected colour scale is the same in the three views, the EEA scale. The curve of the maximum values has been removed to guarantee a focus on the average yearly trend. Santiago de Compostela has higher values in January and February and then the concentration drops to a very low value for the rest of the year. In the city of Modena, the situation is different, we have lower values in the initial part of the year compared with Santiago de Compostela; However, the values in the rest of the year are higher. Zaragoza has a very constant trend during the year and the NO_2 concentration values are generally lower than in Modena.

Finally, the last graph is the week view. For each month, the graph displays the average concentration of the mean weekdays. In order to evaluate the mean hourly concentration trend, for each pollutant and each day of the week, all the available observations in the selected month of the selected day of the week in each hour are averaged. Moreover, to ensure an easy comparison between the trend of different days of the week, their curves are displayed together in the same graph. The user can also click on the day of the week name to remove it from the graph if necessary. The background of the graph is coloured according to the selected colour scale. For example, in Figure 10, the curves of average days of the week trend for the O_3 pollutant on February 2020 are displayed. The graph is a location statistics view of the city of Zaragoza, the position of the location is indicated in the map on the left corner. In this graph, the curves have all a similar trend lower values at night and higher during the evening hours. However, Wednesday and Thursday had a higher peak than the other days of the week, and Saturday and Sunday instead show higher values during night and morning hours.

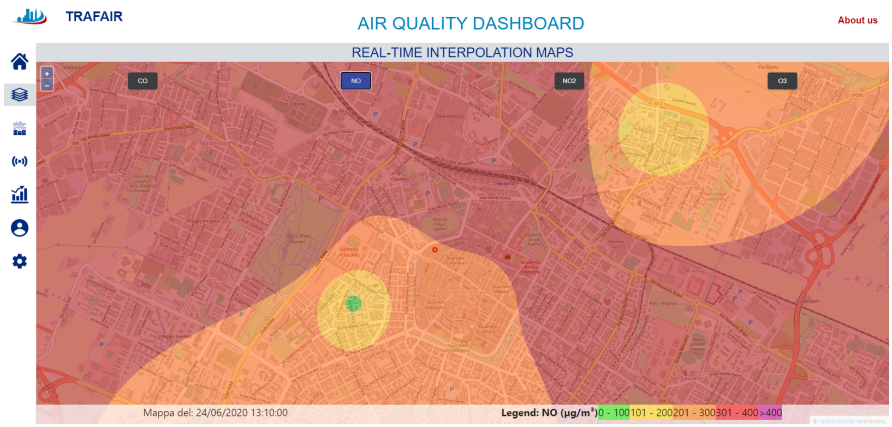

Fig. 11 The interpolation map of NO of 24th June 2020 for the city of Modena at 1:10 pm UTC. The colours are based on the EEA scale.

5.4 Interpolation Maps

The interpolation maps view of the dashboard satisfy the requirement **R4**; the semi-real-time interpolation maps are obtained querying GeoServer layers. As displayed in Figure 11, the interpolation maps view consists of a coloured map with 4 buttons on the top that can be clicked to switch between one pollutant to the others available. The coloured interpolation map obtained as described in Section 3.4 is overlayed on the OSM city map of the area. The style of the map depends on the selected colour scale. This is possible because interpolation maps are saved as raster data. Rasters are generally used to represent space-continuous phenomenons like pollutants concentration. Two different colour scales can generate a very different map and can be used to communicate diverse information. For example, in Figure 12, the same raster map is visualized with two different colour scale. The maps refer to Santiago de Compostela and the top-view shows the interpolation map obtained with the EEA colour scale; The bottom-view, indeed, displays the same interpolation map obtained setting the TRAFAIR customized colour scale. The TRAFAIR colour scale can help to highlight differences in the area since there are more colour bands each one covering a smaller interval of concentration values. Besides, the EEA based map only shows a lighter green area that has a higher value than the rest of the city, while the one based on the TRAFAIR colour scale helps to identify two areas with higher values in a darker shade of blue and one area with a lower concentration of O_3 highlighted in white.

In the left bottom of the view, the timestamp associated with the map is displayed. The maps are updated automatically every 10 minutes.

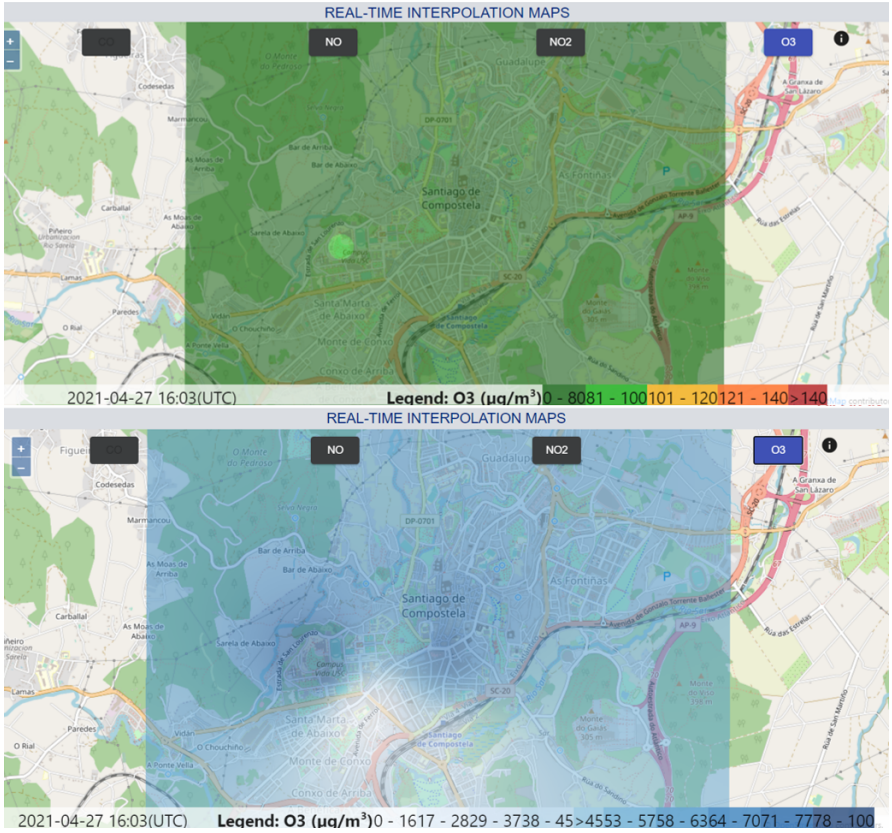

Fig. 12 O_3 interpolation map of Santiago de Compostela on the 27th of April 2021 at 16:03 UTC. The colour scale employed to represent the raster data is the EEA in the top figure, and the TRAFAIR customized colour scale in the bottom figure.

5.5 Prediction Maps

The requirement **R6** is satisfied by the prediction map view. As described in Section 3, data coming from traffic sensors are used to feed a traffic model, then emissions are evaluated and the GRAL dispersion model simulates the movement of the particles and generates 48 images, for each hour of the forecast. These images are saved as raster data that contain information about the forecast of NOx concentration for each 4X4 meters square of the city area. Moreover, when these images are uploaded in GeoServer they are associated with the hour of the day their forecast refers to. Images generated with the same simulation are saved in the same Image Mosaic collection in GeoServer (as described in Section 4.2). The ImageMosaic plugin allows to see the evolution of images over time, the collection of images can be queried to obtain a GIF or a sequence of ordinated images. As can be seen in Figure 13, the view displays a GIF summarizing the evolution of today's air quality forecast. Moreover, the city

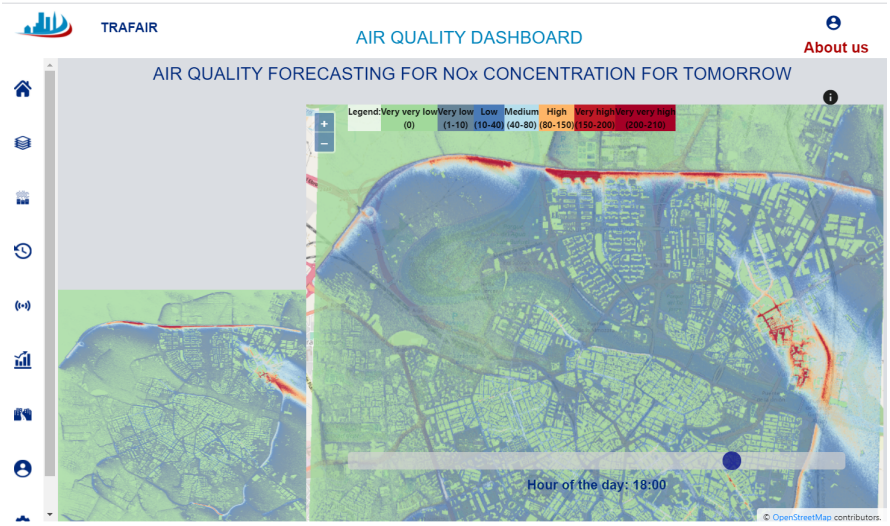

Fig. 13 Prediction view that displays the air quality forecast for today (2021-04-28). The map displays the air quality conditions predicted for 6 PM for the city of Zaragoza.

map is coloured accordingly to the concentration of NOX particles forecasted by the air pollutant dispersion model. The slide bar can be used to move through the time axis and see the evolution of the air conditions during the day. Furthermore, users can interact with the map zooming and moving in the area. In this case, the legend is qualitative because we are communicating a forecast that can contain an error. By clicking on the button 'Tomorrow prevision' the view showing the prevision for tomorrow is displayed.

5.6 New Scenarios

The **R9** requirement asks to compare NOx concentrations in different scenarios. In the Scenario view, the season, the day type (weekday or holiday), and the composition of the vehicle fleet should be selected through a drop-down menu. Whit the collaboration of the public administration members, we define a set of possible scenarios and this view allows comparing the predicted air quality conditions. The sustainability plan inspired the definition of the vehicle fleet options that are different for each city. For example, in the city of Modena, the three possible options are: (i) CURRENT: the actual vehicle fleet composition with a majority of petrol and diesel alimented vehicles, (ii) PAIR 2020: the vehicle fleet inspired by the Integrated Air Plan of the Emilia Romagna region obtained increasing the number of electric and hybrid vehicles, and (iii) PUMS 2030: the future vehicle fleet that the city council wishes to reach in 2030, inspired by the Urban Sustainable Mobility Plan, characterized by a majority of electric and hybrid vehicles. The scenario view shows the

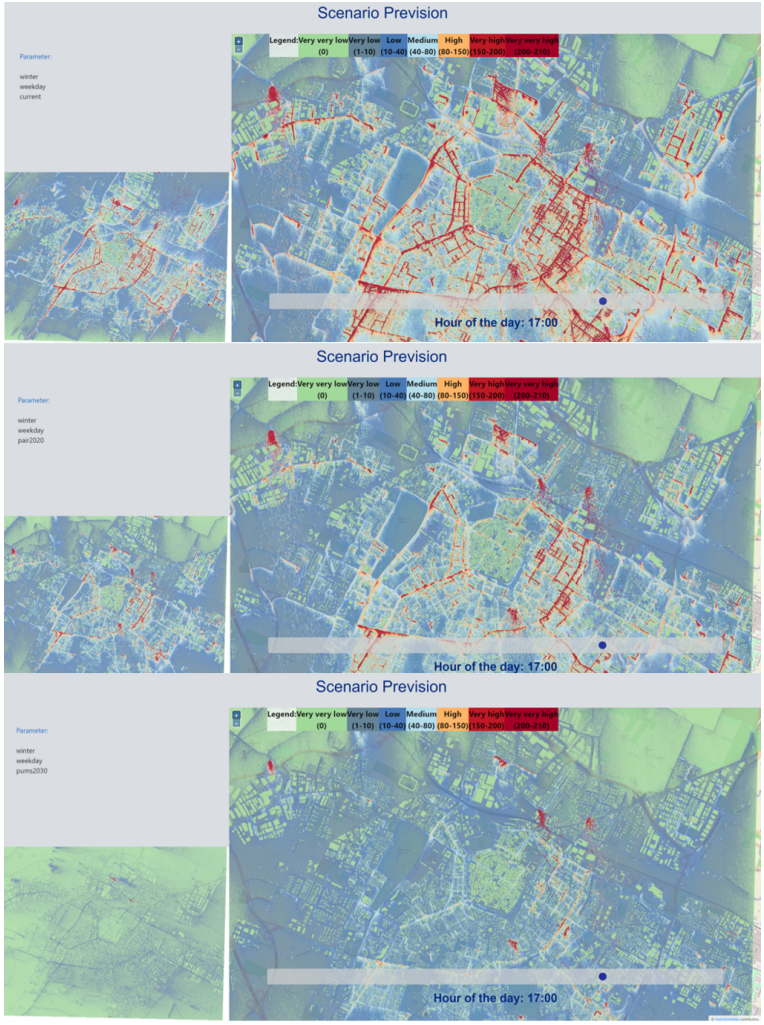

Fig. 14 Comparison of winter weekdays in 3 different scenarios: with current vehicles fleet (top), with Pair2020 vehicles fleet (middle), and with PUMS 2030 vehicles fleet (bottom).The image refers to the city of Modena

composition of the vehicle fleets in a table beneath the drop-down menu windows. Then, once the options have been selected, by clicking on the 'ready' button the prediction of the possible concentration of NOx with the selected vehicle fleet and Similarly to the 'Prediction view', the user can select the hour of the day using the slide bar, and the GIF shows the evolution of the concentration of NO_x during the day. This view allows users to observe the differences in different periods of the year, the difference between weekdays and holidays, the effect of a different vehicle fleet composition on the urban air quality.

This view can be used to see the differences between the period of the year, weekdays, and holidays and the effect of a change in the composition of the vehicle fleet.

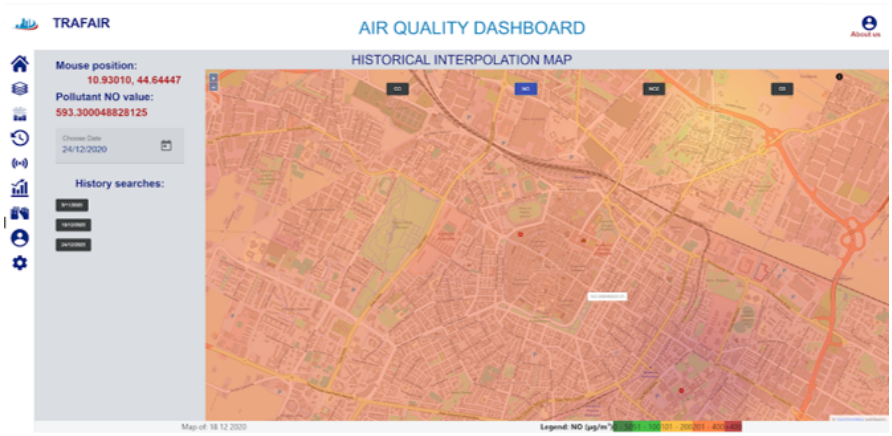

Fig. 15 Historical view of the average daily interpolation map for NO of 17th January 2021 in the city of Modena. The user can move the mouse on the map to see the value of average pollutant concentration in the pointed position.

5.7 Historical maps

Comparing real-time maps with the ones obtained in the past days can help to better understand the current air quality values in the period context. For this reason, the dashboard allows the user to visualize maps of past days. As required by **R7** and **R8**, two main categories of maps are available: Historical Interpolation maps and Historical Prediction maps.

The Historical interpolation maps view enables the users to visualize interpolation maps regarding the past days. These interpolation maps are obtained with a spatial interpolation of the average daily values in each sensor position. The day can be selected from the calendar on the left side of the view (Figure 15). When a day is selected it will be inserted into the history searches so that the user can easily compare several days moving from one to the other. This view shows the average air quality conditions in the whole urban area and enables citizens and public administrations to compare different days of the week and different areas of the city.

The Historical Prevision view allows the user to select a day in the past and see the forecast of NO_x concentration that was produced for that day using the GRAL model. Since GRAL generates 48 hours previsions, for each day, two different forecasts are available: the prevision produced the day before and the prevision produced two

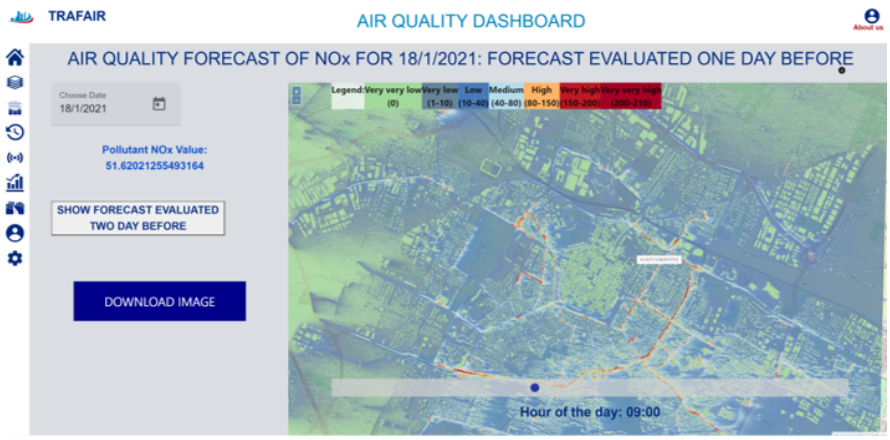

Fig. 16 Air quality forecast for NOx for 18th January 2021 at 09:00 AM in the city of Modena.

days before. Generally, the prevision produced the day before should be the most reliable since the weather forecasts used to simulate the particles' movements are more precise. The user can visualize both of them by clicking on the 'show forecast evaluated the day before' button. An example of this view is displayed in Figure 16. The user can also download and save locally an image of the current map he/she is visualizing. Moving the mouse cursor on the map a label appears with the predicted NO_x concentration value in the pointed position.

6 Conclusion

We presented the TRAFAIR Air Quality dashboard that has been realized within the TRAFAIR project to display real-time, forecast, and statistical air quality observations through graphics, timelines, and maps. It allows decision-makers to monitor air conditions in the city of Modena and analyze trends regarding pollutant concentration. The architecture of the web application enables scalability allowing us to insert new sensors, move sensors around the city in new positions, and collect statistics regarding more months and years. We verify the replicability in different cities of the proposed solution: the dashboard is now in use in the cities of Modena, Santiago de Compostela, and Zaragoza. Through the use of GeoServer, data can be queried as coming from an API with a REST request. This allows us to manage a big amount of data structuring them in different layers and enabling different services on the same storage to obtain images, maps, or numerical values. The response time is reduced by the use of materialized views and automatized processes to update them.

We intend to integrate into the dashboard a combined visualization of air pollution dispersion model results and measured data to provide feedback on the effectiveness of the predictions to refine the model. Moreover, a future improvement of the

dashboard may include the measurement of Particulate Matter (PM) in order to provide an overall air quality index that describes the air quality condition in the cities. This improvement requires additional sensors able to measure PM. Thanks to the experience gained in the context of the visualization of air quality sensor and model data, we create a dashboard that displays traffic data: both data coming from the sensors available in a smart city and data produced by traffic models [26, 13]. We are working on some views that allow visualizing both air quality and traffic conditions to better understand the impact of vehicles emission on the quality of the air in the urban context, an example of this views is included in the TRAFAIR Traffic dashboard described in [27].

Acknowledgment

This research was developed in the scope of the TRAFAIR project 2017-EU-IA-0167), a European project co-financed by the Connecting Europe Facility of the European Union. The contents of this publication are the sole responsibility of its authors and do not necessarily reflect the opinion of the European Union. We kindly thank the City of Modena and Lepida S.c.p.A that both contribute to the management of sensors. Moreover, we acknowledge the important contribution of the LARMA team of the “Enzo Ferrari" Engineering Department for their contribution in installing, maintaining, and calibrating the air quality sensors in the city of Modena. We would like to thanks Jose R.R. Viqueira and Raquel Trillo Lado for contributing to making the dashboard also work in the city of Santago de Compostela and Zaragoza. Finally, we kindly regard Filippo Monelli and Giulio Querzoli for their help with software implementation.

References

1. M. Krzyzanowski and A. Cohen, “Update of who air quality guidelines,” *Air Quality, Atmosphere & Health*, vol. 1, pp. 7–13, 06 2008.
2. C. Bachechi, F. Desimoni, L. Po, and D. M. Casas, “Visual analytics for spatio-temporal air quality data,” in *24th International Conference on Information Visualisation, IV 2020, Melbourne, Australia, September 7-11, 2020*, E. Banissi, F. Khosrow-shahi, A. Ursyn, M. W. M. Bannatyne, J. M. Pires, N. Datia, K. Nazemi, B. Kovalerchuk, J. Counsell, A. Agapiou, Z. Vrcelj, H. Chau, M. Li, G. Nagy, R. Laing, R. Francese, M. Sarfraz, F. Bouali, G. Venturini, M. Trutschl, U. Cvek, H. Müller, M. Nakayama, M. Temperini, T. D. Mascio, F. Sciarrone, V. Rossano, R. Dörner, L. Caruccio, A. Vitiello, W. Huang, M. Risi, U. Erra, R. Andonie, M. A. Ahmad, A. Figueiras, and M. S. Mabakane, Eds. IEEE, 2020, pp. 460–466. [Online]. Available: https://doi.org/10.1109/IV51561.2020.00080
3. P. Chen, “Visualization of real-time monitoring datagraphic of urban environmental quality,” *EURASIP J. Image Video Process.*, vol. 2019, p. 42, 2019. [Online]. Available: https://doi.org/10.1186/s13640-019-0443-6
4. M. Zhou, R. Wang, S. Mai, and J. Tian, “Spatial and temporal patterns of air quality in the three economic zones of china,” *Journal of Maps*, vol. 12, no. sup1, pp. 156–162, 2016.

[Online]. Available: https://doi.org/10.1080/17445647.2016.1187095
5. J. Martorell-Marugán, J. A. Villatoro-García, A. García-Moreno, R. López-Domínguez, F. Requena, J. J. Merelo, M. Lacasaña, J. de Dios Luna, J. J. Díaz-Mochón, J. A. Lorente, and P. Carmona-Sáez, "Datac: A visual analytics platform to explore climate and air quality indicators associated with the covid-19 pandemic in spain," *Science of The Total Environment*, vol. 750, p. 141424, 2021. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0048969720349536
6. X. Wu, A. Poorthuis, R. Zurita-Milla, and M. Kraak, "An interactive web-based geovisual analytics platform for co-clustering spatio-temporal data," *Comput. Geosci.*, vol. 137, p. 104420, 2020. [Online]. Available: https://doi.org/10.1016/j.cageo.2020.104420
7. S. Stehle and R. Kitchin, "Real-time and archival data visualisation techniques in city dashboards," *Int. J. Geogr. Inf. Sci.*, vol. 34, no. 2, pp. 344–366, 2020. [Online]. Available: https://doi.org/10.1080/13658816.2019.1594823
8. C. Jing, M. Du, S. Li, and S. Liu, "Geospatial dashboards for monitoring smart city performance," *Sustainability*, vol. 11, p. 5648, 10 2019.
9. S. Guptill, "Spatial data," in *International Encyclopedia of the Social and Behavioral Sciences*, N. J. Smelser and P. B. Baltes, Eds. Oxford: Pergamon, 2001, pp. 14 775–14 778. [Online]. Available: https://www.sciencedirect.com/science/article/pii/B0080430767025080
10. G. Chatzigeorgakidis, K. Patroumpas, D. Skoutas, S. Athanasiou, and S. Skiadopoulos, "Scalable hybrid similarity join over geolocated time series," in *Proceedings of the 26th ACM SIGSPATIAL International Conference on Advances in Geographic Information Systems*, ser. SIGSPATIAL '18. New York, NY, USA: Association for Computing Machinery, 2018, p. 119–128. [Online]. Available: https://doi.org/10.1145/3274895.3274949
11. L. Po, F. Rollo, J. R. R. Viqueira, R. T. Lado, A. Bigi, J. C. López, M. Paolucci, and P. Nesi, "Trafair: Understanding traffic flow to improve air quality," in *2019 IEEE International Smart Cities Conference, ISC2 2019, Casablanca, Morocco, October 14-17, 2019*, 2019, pp. 36–43.
12. C. Bachechi and L. Po, "Implementing an urban dynamic traffic model," in *2019 IEEE/WIC/ACM International Conference on Web Intelligence, WI 2019, Thessaloniki, Greece, October 14-17, 2019*, P. M. Barnaghi, G. Gottlob, Y. Manolopoulos, T. Tzouramanis, and A. Vakali, Eds. ACM, 2019, pp. 312–316. [Online]. Available: https://doi.org/10.1145/3350546.3352537
13. L. Po, F. Rollo, C. Bachechi, and A. Corni, "From sensors data to urban traffic flow analysis," in *2019 IEEE International Smart Cities Conference, ISC2 2019, Casablanca, Morocco, October 14-17, 2019*, 2019, pp. 478–485. [Online]. Available: https://doi.org/10.1109/ISC246665.2019.9071639
14. P. Bellini, S. Bilotta, P. Nesi, M. Paolucci, and M. Soderi, "Wip: Traffic flow reconstruction from scattered data," in *2018 IEEE International Conference on Smart Computing (SMARTCOMP)*, 2018, pp. 264–266.
15. P. Á. López, M. Behrisch, L. Bieker-Walz, J. Erdmann, Y. Flötteröd, R. Hilbrich, L. Lücken, J. Rummel, P. Wagner, and E. WieBner, "Microscopic traffic simulation using SUMO," in *21st International Conference on Intelligent Transportation Systems, ITSC 2018, Maui, HI, USA, November 4-7, 2018*. IEEE, 2018, pp. 2575–2582.
16. G. Veratti, "The development of a building-resolved air quality forecast system by a multi-scale model approach and its application to modena urban area," dissertation, University of Modena and Reggio Emilia, 2020. [Online]. Available: https://iris.unimore.it/retrieve/handle/11380/1200723/261485/
17. A. Bigi, G. Veratti, S. Fabbi, L. Po, and G. Ghermandi, "Forecast of the impact by local emissions at an urban micro scale by the combination of lagrangian modelling and low cost sensing technology: The trafair project," in *19th International Conference on Harmonisation within Atmospheric Dispersion Modelling for Regulatory Purposes, Harmo 2019*, 2019.
18. S. Fabbi, S. Asaro, A. Bigi, S. Teggi, and G. Ghermandi, "Impact of vehicular emissions in an urban area of the po valley by microscale simulation with the gral dispersion model," *IOP Conference Series: Earth and Environmental Science*, vol. 296, p. 012006, 07 2019.

19. J. Li and A. D. Heap, "Spatial interpolation methods applied in the environmental sciences: A review," *Environmental Modelling & Software*, vol. 53, pp. 173 – 189, 2014. [Online]. Available: http://www.sciencedirect.com/science/article/pii/S1364815213003113
20. S. Iacovella, *GeoServer Cookbook*. Packt Publishing, 2014.
21. J. Nogueras-Iso, H. Ochoa-Ortiz, M. A. Janez, J. R. R. Viqueira, L. Po, and R. Trillo-Lado, "Automatic publication of open data from ogc services: the use case of trafair project," 2020, manuscript submitted for publication in The Twelfth International Conference on Advanced Geographic Information Systems, Applications, and Services GEOProcessing 2020.
22. N. Jain, A. Bhansali, and D. Mehta, "Angularjs: A modern mvc framework in javascript," *Journal of Global Research in Computer Science*, vol. 5, no. 12, pp. 17–23, 2014.
23. M. Bostock, V. Ogievetsky, and J. Heer, "D3 data-driven documents," *IEEE Transactions on Visualization and Computer Graphics*, vol. 17, no. 12, p. 2301–2309, Dec. 2011. [Online]. Available: https://doi.org/10.1109/TVCG.2011.185
24. "Chart.js | open source html5 charts for your website," http://www.chartjs.org#Dataviz, 2017, accessed: 2020-07-15.
25. F. Rollo and L. Po, "Senseboard: Sensor monitoring for air quality experts," in *Proceedings of the Workshops of the EDBT/ICDT 2021 Joint Conference, Nicosia, Cyprus, March 23, 2021*, ser. CEUR Workshop Proceedings, C. Costa and E. Pitoura, Eds., vol. 2841. CEUR-WS.org, 2021. [Online]. Available: http://ceur-ws.org/Vol-2841/BigVis_3.pdf
26. C. Bachechi, F. Rollo, F. Desimoni, and L. Po, "Using real sensors data to calibrate a traffic model for the city of modena," in *Intelligent Human Systems Integration 2020 - Proceedings of the 3rd International Conference on Intelligent Human Systems Integration (IHSI 2020), February 19-21, 2020, Modena, Italy*, 2020, pp. 468–473. [Online]. Available: https://doi.org/10.1007/978-3-030-39512-4_73
27. F. R. Chiara Bachechi, Laura Po, "Big data analytics and visualization in traffic monitoring," *Big Data Research*, to appear.