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Societal Challenge: Improving the air quality and reducing the carbon footprint of European cities

Project: 690105 – ICARUS

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Integrated Climate forcing and Air pollution Reduction in Urban Systems

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Executive summary

Four special issues on ICARUS results and the overall topic of air pollution abatement and climate change mitigation will be released in the first part of 2021 based on the works presented at the ICARUS Final Conference organized on the 26th and 27th October 2020 in the frame of the 20th MESAEP Symposium and on additional work developed through the project.

Depending on the paper the journal addressed will be any of the four below:

- Fresenius Environmental Bulletin (FEB), the official journal of the MESAEP Conference – Guest editor: Prof. D. Sarigiannis.
- Environmental Research – Guest editor: Prof. D. Sarigiannis, Dr. A. Gotti, Dr. S. Karakitsios. About the latter we have already the agreement of the Editor in Chief Prof. Louis Domingo.
- Applied Sciences - Special Issue "Air Pollution: From Source Apportionment to Climate Change and Health Impact Assessment" (Guest Editor: Dr. Thomas Maggos, Dr. D. Saraga)
- Applied Sciences - Special Issue "Advances in Air Quality Monitoring and Assessment" (Guest Editor: Dr. Thomas Maggos)

During the ICARUS Final Conference fourteen presentations (eleven oral and three poster) were given by ICARUS consortium members to the participants to illustrate key findings and main impacts of the project activities. All the abstracts submitted acknowledge the ICARUS project and the funding source. The abstracts underwent a double-blind peer review process, where each abstract was evaluated by two independent reviewers before being accepted for the conference.

The scientific contributions of the ICARUS consortium members were overall of high level and explored very pertinent environmental and societal issues to which current science strives to produce a comprehensive evidence basis. To this end the ICARUS community produced very relevant research results that address some of the most important questions regarding environment, sustainability and life quality. Significant effort has been also made to render these findings understandable and usable by decision-makers to promote evidence-based policy in environmental and life quality protection.

In the next section all the abstracts submitted and accepted are reported. It is worth mentioning all these abstracts were included in the official MESAEP Book of Abstracts edited by D. Sarigiannis, D. Seker, A. Gotti, M. Zucchetti and already published (ISBN 9781005202804).

ICARUS Abstracts presented at the ICARUS session of MESEAP 2020

ID 87 - Transition to Climate Friendly and Unpolluted Cities until 2050

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Many cities in Europe and beyond have very ambitious climate protection goals, e.g. becoming carbon-free by 2050. At the same time cities are striving for meeting ambitious air pollution control aims, especially for PM2.5 and NO2; it is very likely, that the European Commission will decrease the PM2.5 limits further, so that the aims for air pollution control will get more ambitious. Currently, separate plans for climate protection and air pollution control are prepared. However, as measure for air pollution control also influence greenhouse gas emissions and vice versa, it is obvious that a common plan for climate protection and air pollution control would result in more efficient bundles of measures. Thus we strive here for developing visions for cities, where greenhouse gas emissions are reduced by 95-100% (not allowing for carbon leakage) and simultaneously the WHO target values for air quality, e.g. 10 $\mu g/m^3$ PM2.5 annual mean, are not exceeded. These aims should be fufilled in such a way that the costs and utility losses should be minimised and thus wellbeing and quality of life of the population is maximized. First, the technical options that might be used to meet the above mentioned aims are described. The main secondary energy carrier will be electricity produced with CO2-free power plants.

As the production from solar and wind energy is fluctuating and storage of electricity is expansive, some electricity will be used to produce hydrogen, which will be the second important energy carrier. Hydrogen might be stored and distributed in the retrofitted natural gas network. Biomass (wood, biogas,) is used to less extent. The potential is limited and in small combustion systems the emissions of pollutants are too high, so biomass may only be used in larger units with very good filters. The modes for transport used include autonomously driving interconnected vehicles (cars, small busses and trucks), rail-bound transport systems, walking and cycling.

Cities are divided into mixed zones and into fast lanes, where transport modes are separated. Options for private transport include private 'taxis' for only one party and small busses (6-8 places), that simultaneously pick up people from and transport people to different places along the route. However, simulations show, that to avoid traffic jams during rush hours, rail-bound traffic is necessary in addition to taxis and small buses. With regard to the building stock, it is essential that all buildings are highly heat insulated.

Our simulation here shows, that especially replacing windows makes the buildings tighter and so indoor pollution is increasing. Thus all buildings should be equipped with a mechanical ventilation system with heat recovery. A larger number of techniques for heat production is available: electric heat pumps - where possible combined with photovoltaik cells on the roof, combined heat and power units, fuel cells and condensing boilers using hydrogen, district or block heating and cooling a.s.o.

The concept described above is analysed quantitatively for the city of Stuttgart and indicator values for the realisation of the concept in 2050 are given. E. g. the number of vehicles will be drastically reduced. If the concept with private 'taxis' is realised, the necessary number of vehicles will be halved. With small buses, only 20% of the vehicles driving now through the city are needed. Thus a combined system with ride sharing during rush hours and car sharing outside the rush hours might be an optimal system. Variable pricing may be used to steer the behaviour of the transport users. Less cars also mean less occupied parking space on the streets leaving free spaces for other purposes.

Acknowledgement: This work has received funding from the European Union's Horizon 2020 under grant agreement No 690105 (Integrated Climate forcing and Air pollution Reduction in Urban Systems (ICARUS)

Keywords: CO2-free city, clean air in cities, green cities

ID 129 - Uncertainty associated with assessing personal exposure to particulate matter with high temporal resolution using low-cost portable sensors

Rok Novak[1], David Kocman[1], Tjaša Kanduč[1], Milena Horvat[1], Johanna Amalia Robinson[1], Dimosthenis Sarigiannis[2]

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Summary

Combining particulate matter (PM) concentration and heart rate (HR) data from low-cost sensors can provide personal exposure information with high temporal resolution. Uncertainty associated with low-cost sensors was determined by collocating them with reference instruments, and using this data to model personal exposure to PM. Four models were used with different levels of complexity (in reference to the variables implemented in the model). The results showed that the more complex models, using HR, sex, ethnicity and other variables as proxies to determine minute ventilation, responded better to changes in activity and provided data with less uncertainty. Low-cost sensors could be used for modelling personal exposure to particulate matter.

Introduction

Exposure to PM has been linked to several health issues and a key step in understanding, and subsequently reducing its impact on health, is to accurately measure exposure on a personal level. Low-cost sensors facilitate extensive studies which can provide data with high-temporal and spatial resolution, but come with certain shortcomings stemming from simplified sensing technologies. Personal exposure calculations from this data have uncertainties which differ according to the type of model used. Several models were used to calculate personal exposure from heart rate and PM concentration data. Uncertainties associated with these models were compared to determine which variables have the highest impact on the uncertainty in each approach.

Methodology and Results

A portable low-cost PM sensor was used to measure concentrations with high temporal resolution (1 min) for one week in the spring of 2019. Prior to using this sensor in field conditions, it was validated and the results showed that the PM1 data had relatively low uncertainty. HR was used as a proxy for calculating minute ventilation, and was measured by a low-cost activity tracker.

Four models were used to determine personal exposure to PM (from most to least complex): 1. using HR, sex, ethnicity and age (Greenwald et al., 2019); 2. using HR and sex (Zuurbier et al., 2009); 3. using sex, age, body weight, microenvironment characteristics (Madureira et al., 2018); 4. using age and sex, and determining minute ventilation by using average values for specific age groups. Two models did not use HR as input data. The results showed that models 1 and 2 had similar patterns and were mostly in agreement, except at elevated concentration levels. Model 3 mostly followed the pattern from models 1 and 2, but also had some high deviations, which were even more evident at higher concentrations of PM. Model 4 did provide some correction to the raw PM data, but proved to be relatively unresponsive to changes in activity, compared to other models.

Conclusions
The models used for calculating personal exposure proved to differ, mostly based on the number of considered variables. Models 1 and 2, which used HR as a proxy for minute ventilation, provided data that mostly corresponded with changes in activity and PM concentrations, and the models that did not use HR, showed less response to changes. This research showed that models which use data for multiple variables, which can also be obtained from non-intrusive low-cost sensors, have less uncertainty. Further research is also needed to validate modelled exposure with directly measured personal exposure.

Acknowledgement
This project has received funding from the European Union's Horizon 2020 research and innovation programme (ICARUS project) under grant agreement No 690105 and of the core facilities of the "Jožef Stefan" Institute.

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Madureira, J., Aguiar, L., Pereira, C., Mendes, A., Querido, M.M., Neves, P., Teixeira, J.P., 2018. Indoor exposure to bioaerosol particles: levels and implications for inhalation dose rates in schoolchildren. Air Qual Atmos Health 11, 955–964.

Zuurbier, M., Hoek, G., Hazel, P. van den, Brunekreef, B., 2009. Minute ventilation of cyclists, car and bus passengers: an experimental study. Environmental Health 8, 48.

Keywords: particulate matter, minute ventilation, dose assessment, low-cost sensors, uncertainty assessment

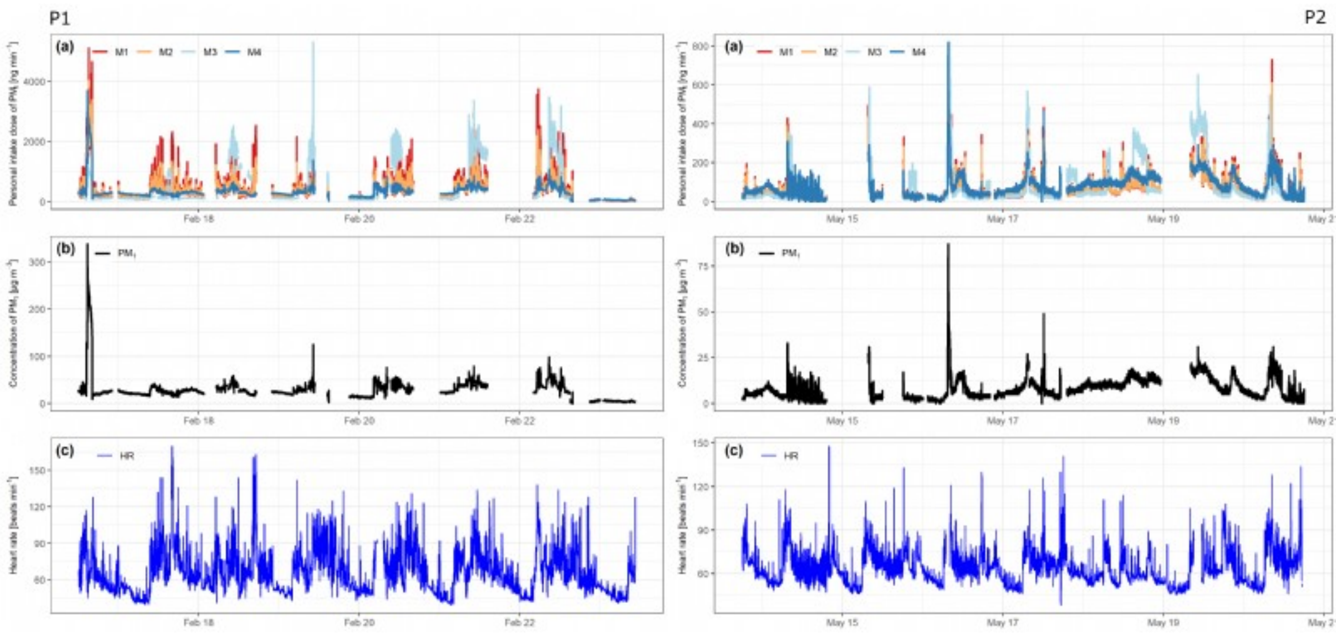

Figure 1. (a) Calculated intake dose of PM_1 for all four models, (b) measured concentrations of PM_1, (c) heart rate in beats per minute. Left side for participant 1 (P1) and right side

ID 131 - Cost-benefit analysis of carbon mitigation measures in European cities: the importance of co-benefits

Tim Taylor[1], Anna Maccagnan[1], Denis Sarigiannis[2], Alberto Gotti[3], Francesca Bugnoni[3], Marco Persico[3], Jaideep Visave[3], Julia Neuhäuser[4], Rainer Friedrich[4], Danielle Vienneau[5], Benjamin Flückiger[5], Jan Harnych[6], Katerina Maneva Mitrovikj[6], Jiři Spitz[6], Ondřej Mikeš[7], Céline Degrendele[7], Anastasia Gkika[8], John Bartzis[9], Ioannis Sakellaris[9], Davor Kontić[10]

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This study has been developed within the European Union funded Horizon 2020 project Integrated Climate forcing and Air pollution Reduction in Urban Systems (ICARUS). In this study we apply cost-benefit analysis (CBA) and cost-effectiveness analysis to evaluate some carbon mitigation strategies which have been proposed by the cities within the ICARUS project. The selected measures relate to three broad areas: energy efficiency measures, in the form of heating system replacement and building insulation investments (Basel, Brno and Stuttgart); active transportation measures, i.e. promotion of walking, cycling and public transportation (Athens, Brno and Stuttgart); and alternative fuel vehicles, particularly private cars and public buses (Brno, Milan and Stuttgart). The quantification of health benefits builds upon a health impact assessment (HIA) of the selected measures. The HIA models the complex process that goes from individual exposure to different pollutants to short-term and long-term health effects. The following health impacts from exposure to PM and NO2 are included in the analysis: adult mortality, infant mortality, Chronic bronchitis, Chronic bronchitis in children aged 6 to 12, Cardiac hospital admissions, Respiratory hospital admissions, and Bronchitis symptoms in asthmatic children aged 5 to 14. In order to input a monetary value to non-tangible impacts, the following assumptions have been made:

- Health Endpoint valuation. The valuation of health endpoints builds on previous studies, and in particular on Hunt et al. (2011) that presents values for a range of health endpoints.
- Carbon savings. The Social Cost of Carbon (SCC) is set at $31 (€201829.03) as suggested by a study by Nordhaus (2017).

- Health benefits from increased walking and cycling. Health benefits linked to the increased cycling and walking are measured using the WHO-Europe (2014) Health Economic Assessment Tool - HEAT for walking and cycling. The benefit of increased physical activity is measured in terms of number of deaths avoided, using the value of a statistical life in the selected country.

- Noise, Accidents and Travel Time Losses. A number of impacts are included in the valuation of some of the measures. First, noise reduction benefits, which can emerge in the case of traffic reductions or in the case of switching from conventional cars to electric vehicles. Second, accidents costs and benefits which can emerge in the case of traffic reductions or in the case of switching to different transport methods. Accident costs include material damages, medical costs, cost of lives lost, cost of loss of productivity and cost of suffering (Gössling et al. 2019). Third, travel time costs, as shifting from personal car use to public transport, walking or cycling is associated to extra travel time. Several parameters have been suggested in the literature to value these co-impacts. An example is the study by Litman and Doherty (2011), which we follow in this study.

Our analysis shows the importance of the inclusion of health co-benefits in economic analysis of carbon mitigation strategies. Options that may appear costly in terms of the financial cost per tonne of carbon reduced become viable in many cases when co-benefits are considered. Different strategies in different cities may be appropriate. It is therefore important to define a policy at an appropriate scale (the urban level) to address carbon mitigation.

Acknowledgements:
This work was carried out within the project within the European Union funded Horizon 2020 project “Integrated Climate forcing and Air pollution Reduction in Urban Systems - ICARUS” (Grant agreement No. 690105).

Keywords: cost-benefit analysis, carbon mitigation, health co-benefits, energy efficiency, active transport, electric vehicles

ID 135 - Development of an integral modeling system to study air quality climatic trends in European urban areas

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Trying to model future climatic change impact on local scale air quality, one should be aware of the inherent difficulties in trying to mathematically describe the associated phenomena and quantify the relevant input due mainly to lack of knowledge and missing accurate enough input data. For answers that require high temporal and spatial refinements the issue of computational capacity must also be considered. Moreover, consideration should be given to the additional difficulty due to high temporal variability of the defining parameters not only on the level of hour and day but also on the level of the year and even beyond. Within the frame of the European Project ICARUS, the present work aimed at building a comprehensive integral modeling system to study air quality climatic trends in European urban areas coping with the above-mentioned difficulties as successfully as possible. For air quality modeling on the urban scale both WRF-Chem and CAMx models have been utilized offering capability of results intercomparison and inherent model uncertainty. Concerning emissions input, the University of Stuttgart (USTUTT) High Resolution (1km x 1km) Emission Inventory Scenarios Data produced within ICARUS Project, have been postprocessed. To study air quality climatic trends (a) the climatic period (e.g., 2001-2050) together with the specific climatic scenario coming from Representative Concentration Pathway (RCP) are selected. (b) All days of the above climatic period are grouped using weather cluster methodology (c) for a given climatic period interval (e.g. 5 years) cluster based representative days are selected on one hand for performing detailed air quality modelling simulations and on the other hand for selecting appropriate boundary conditions for those simulations and (d) Pollutant Representative concentration (CR) indicators per climatic time interval indicators are estimated based on the above mentioned detailed simulations. The present methodology has been applied for the city of Thessaloniki selecting the moderate RCP4.5 climatic scenario for the period 2001-2050. The weather clustering has been performed using modelling data from the Coordinated Regional Climate Downscaling Experiment (CORDEX) provided from the Earth System Grid Federation (ESGF) index nodes with 10km space resolution. In addition, comparisons of the obtained modelling concentration data with available experimental data where feasible, are presented and discussed.

Acknowledgement: This work has received funding from the European Union's Horizon 2020 under grant agreement No 690105 (Integrated Climate forcing and Air pollution Reduction in Urban Systems (ICARUS)
Keywords: air quality, modeling, urban areas, weather clustering, climatic trend.

ID 140 - Multi-sensor data collection for personal exposure monitoring: ICARUS experience

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As part of the ICARUS (Integrated Climate forcing and Air pollution Reduction in Urban Systems) H2020 EU project, sampling campaigns took place in seven European cities (Athens, Basel, Brno, Ljubljana, Madrid, Milan, Thessaloniki), aiming to characterize urban population exposure to air pollutants.

The main objectives of these campaigns were to: (i) collect data on external environmental exposure and exposure determinants by combining location, activity and air pollution data in different microenvironments, (ii) demonstrate feasibility of using new sensor and mobile technologies in collecting exposure data, and (iii) analyse and compare exposure data in several different European cities.

To this end, over 600 participants from over 250 households were recruited altogether in these cities, comprising individuals of all ages and all socioeconomic groups. The process included both at home and personal monitoring for 7 days, including a weekend, in both summer and winter periods. Information was collected using a combination of exposure monitoring devices, questionnaires and time activity diaries. In addition to static sensors placed at volunteers' households, wearable sensors enabled dynamic measurement of personal exposure, location and intensity of activity. Participants were also asked to provide information on their household characteristics, time-use patterns and socioeconomics background. Through the internet of things and taking advantage of WiFi and LoRaWAN communication protocols, data from multiple devices were wirelessly synchronized and uploaded to an online data collection platform. Combining spatiotemporal information on air pollution and activity data of individuals, we were able to directly calculate individual exposure profiles and to aggregate information according to specific microenvironments and activity, respectively. Personal exposure reports were then prepared and distributed to all participants. In the next step, these data will be used to parameterize and validate various simulation models (e.g. Agent Based Models) (Figure 1).

In addition to exposure assessment results (example given in Figure 2), in this presentation the overall experience gained through conduction of sampling campaigns in all seven cities will be summarised, focusing on the following aspects: sensors selection and evaluation, development of the overall study design, data harmonisation and building of supporting ICT infrastructure, as well as overall feasibility evaluation including user experience as reported by both participants and field workers.

Acknowledgement:

This work has received funding from the European Union's Horizon 2020 Programme for research, technological development and demonstration under grant agreement No 690105 (Integrated Climate forcing and Air pollution Reduction in Urban Systems (ICARUS). This work reflects only the authors' views and the European Commission is not responsible for any use that may be made of the information it contains.

Keywords: multi-sensors, air quality, personal exposure, IT infrastructure, user experience

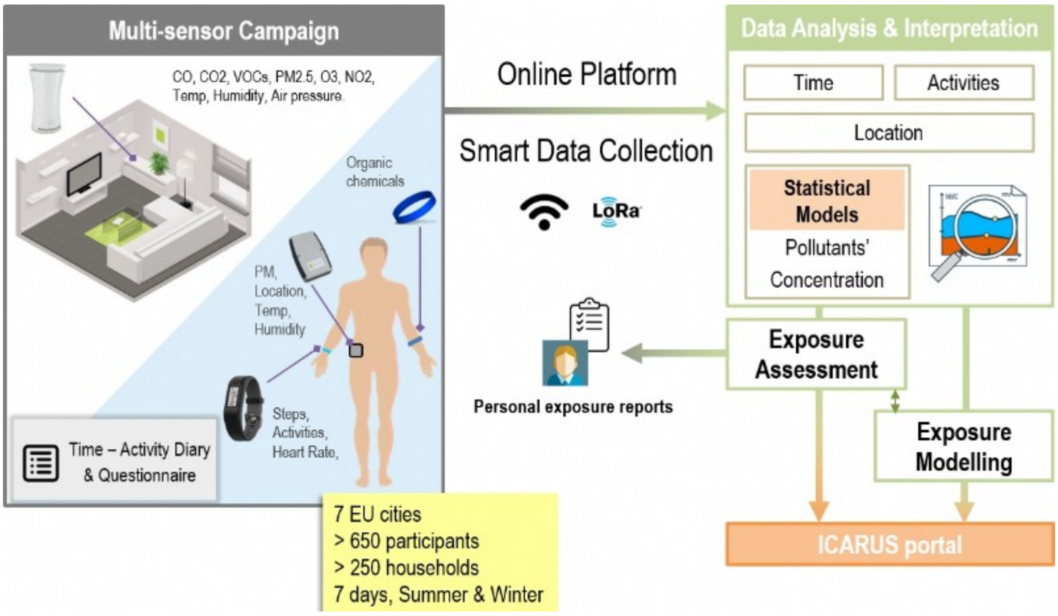

Figure 1. Schematic outline of the ICARUS sampling campaign

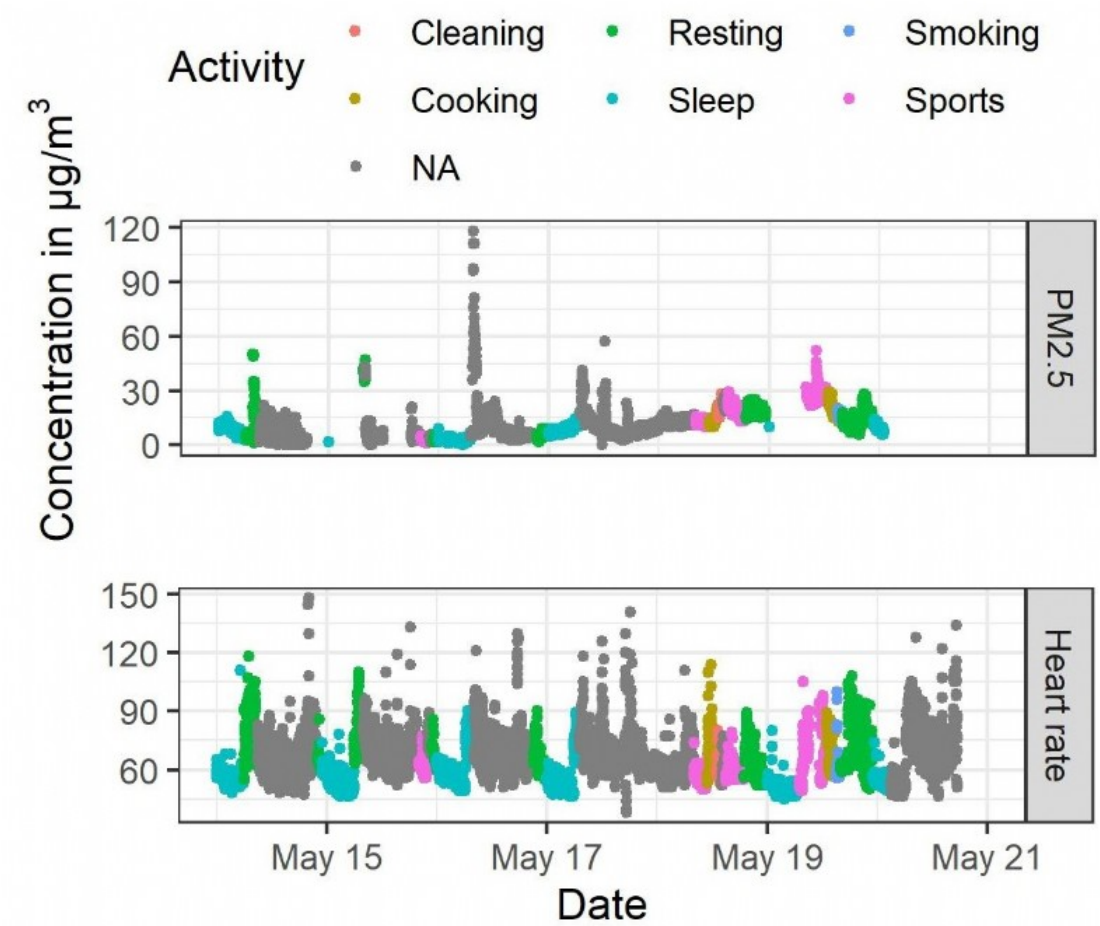

Figure 2. Example of exposure assessment results: PM2.5 concentrations and hearth rate

obtained by wearable sensors over a period of one week with indicated activities of volunteer

ID 156 - Air pollution health impact assessment and cost-benefit analysis of win-win policy solutions at the urban scale in the city of Milan

Marco Giovanni Persico[1], Alberto Gotti[2], Francesca Bugnoni[2], Jaideep Visave[2], Spyros Karakitsios[4], Ioannis Sakellaris[5], John Bartzis[5], Julia Neuhaeuser[6], Rainer Friedrich[6], Anna Maccagnan[7], Tim Taylor[7], Dimosthenis Sarigiannis[3]

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Summary

This study aims at presenting the results of air quality improvements on the environment and human health brought by the potential implementation of five selected policy options as win-win solutions at the urban scale in the city of Milan (Italy). To this end, for each of the selected policy, the following effects have been evaluated: (a) change in emissions of major air pollutants; (b) change in emissions of greenhouse gases (GHGs); (c) changes in ambient concentration of air pollutants; (d) changes in the exposure to air pollutants; (e) changes in the associated impacts on human health; (f) cost-benefit analysis and cost-effectiveness analysis. The impacts of the five selected policy options were carried out under the assumption of RCP4.5 scenario for climate change.

Introduction

Many cities worldwide are affected by air pollution, while being themselves major contributors to the emissions of air pollutants and GHG. Effective policies and measures to reduce emissions have to consider the interest of citizens for clean air and rely on the feasibility of interventions designed to achieve these goals. Numerous epidemiological studies have found an association between air pollution and a wide range of adverse health effects in the general population; the effects have ranged from subtle subclinical effects to premature death. Air Pollution Health Impact Assessment (AP-HIA) aims to estimate the risks of past, current or future exposure to air pollution and of changes in exposure that may result from planned policies or policy options together with the Cost-Benefit Analysis (CBA) and Cost-Effectiveness Analysis, specifically taking into account the impacts of air pollution as well as the GHGs on health and the environment of the measures and policies.

Methodology and Results

Spatially distributed (1*1 km) business-as-usual (BAU) emission inventories for the major air pollutants were developed for years 2015, 2020 and 2030 for the city of Milan. The emissions values (E) were disaggregated by sector groups/subgroups/activities and by type of fuel based on the expected changes in activities (A) and emission factors (EF) for each sector (E = A * EF). The derived emission inventories fed the WRF-Chem model to estimate air pollution concentration levels. According with Milan city stakeholders, five key policies/measures with different time horizons (2020-2030) aiming at reducing air pollutants and GHGs emissions in different sectors were selected: TRANSPORTS (1) Low Emission Zone (Area B) and (2) Conversion of all public buses to electric ones; BUILDINGS (3) Improvement of energy efficiency in existing and new residential flats; ENERGY SUPPLY (4) Photovoltaic, solar power and district heating; LAND USE (5) Planting of 25,000 new trees per year. The new emission inventories for each policy have been provided to the WRF-Chem model to estimate changes in the air concentration levels with respect to the BAU scenarios. Area B, Electric Bus and Building scenarios resulted in lower NO2 levels, in particular Area B showed a significant reduction also for PM2.5 concentrations. Health impact assessment was based on the population attributable risk fraction concept making use of the HRAPIE concentration-response (C-R) functions (WHO, 2013). Results showed: (a) the implementation of a Low Emission Zone (Area B) banning the entrance of the most polluted vehicles shows by far the highest health benefit (between 5 and 18 less mortality cases on yearly basis); (b) Electric Bus and Building scenarios show higher health benefits among the other measures (between 2 and 5 less mortality cases on yearly basis); (c) all policies simulated show the highest health impacts in the periods 2031- 2035 and 2036-2040 and the lowest ones in the period 2021-2025 most likely due to partial implementation of the analysed policies as well as the prevalent meteorological conditions, which may favour pollutant dispersion across less populated areas. CBA compares costs and benefits of a measure by taking an "incremental approach", which means that costs and benefits are computed with respect to the baseline scenario. All costs and benefits are expressed in a common metric, i.e. in monetary values. CBA takes into account both the financial and economic costs and benefits and the performance of the measures presented in table 1 were analysed by computing the Net Present Value (NPV) of total discounted costs and benefits and the Benefit-to-Cost Ratio. Additionally, Cost-effectiveness analysis compared the costs of a measure with the achieved outcomes. Two main indicators of cost-effectiveness were computed and presented to compare costs per tonnes of CO2 eq saved, with respect to the baseline scenario: Financial cost-effectiveness (FICOSTEF), i.e. the financial cost per tC saved, and Full cost-effectiveness (FUCOSTEF), i.e. the full cost (costs-benefit) per tC saved.

Conclusions

An AP-HIA can aid to answer specific policy questions, in many countries it is required as part of the decision-making process for new programmes, projects, regulations, and policies aimed at improving AQ or that may affect AQ as a side-effect. The findings, as an integrated policy assessment, provides a synthesis in terms of decision-making support for the considered policy areas. Based on these results, further cost-benefit analysis has been performed taking into account additional economic, political and social factors, including costs for the emission source operator and for other actors of society, including health impacts, time losses or gains and wider impacts, finally creating a useful tool for policy makers and for an improved compliance to the measures by citizens.

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Keywords: Air Pollution, Health Impact Assessment, policies, emissions

ID 162 - Fine particulate matter chemical composition and sources in 6 European cities: The ICARUS Project

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Particulate matter air pollution deriving from traffic, industrial emissions, oil combustion, biomass burning and other anthropogenic activities as well as natural sources comprises one of the major global concerns. PM2.5 is an air pollution metric widely used to assess air quality, with the EU having set targets for reduction in PM2.5 levels and population exposure. Consequently, one of the major challenges for the scientific community is to identify, quantify and characterize, at the appropriate scale, the sources of atmospheric particles in the aspect of proposing effective control strategies to the public authorities. Although studies for source apportionment are rapidly spreading globally, revealing both PM local and regional origin, the comparability of results among the different sampling sites is often hampered, leading to the need for harmonized source apportionment outcomes from multi-city studies. This study presents the results from PM2.5 data collected in six European cities (Athens, Brno, Ljubljana, Madrid, Stuttgart and Thessaloniki) in the frame of H2020 ICARUS project, their chemical composition as well as the outcomes of source apportionment application. In particular, PM2.5 samples collected from three different sites in each city (traffic, urban background and rural) were chemically analyzed for ions, heavy metals, organic/elemental carbon (OC/EC) and Polycyclic Aromatic Hydrocarbons (PAHs). The chemical composition data was introduced in PMF (Positive Matrix Factorization) and Lenschow approach models with the scope of identifying the main groups of sources and estimating their contribution to PM2.5 concentrations.PM2.5 limit value (WHO daily limit: 25μg/m3; annual EU target value: 25μg/m3) was exceeded in 50% of the sampling days at Athens' sites, 10-28% at Brno sites, 20-48% at Ljubljana sites, 8-37% at Thessaloniki sites. The exceedances at Madrid and Stuttgart sites were less than 7% of the sampling period. It is remarkable that the majority (>70%) of the exceedances were recorded during the winter period.

EPA PMFv.5 and Lenschow approach models were run for each sampling site/city (n=60 samples per site, including warm and cold season). Depending on the case, PMF model resulted in a number of five to eight PM2.5 sources for each site/city. Biomass combustion contribution to PM2.5 (11-43%) indicated the prevalence of the source during winter/fireplaces-burning periods, without excluding biomass combustion emissions from agricultural activities. Fuel oil combustion source (contribution 8-27%) presented almost similar factor profiles among the sites but different temporal variation. In the majority of the cases, traffic was represented by two different factors: traffic-exhausts and traffic non-exhausts. Traffic-exhausts contribution ranged between 6% (Thessaloniki rural) and 32% (Ljubljana traffic site). In all cases, the source contribution was higher at the traffic sites of the cities except for Athens, where the maximum value was found for rural site, where frequent transit of heavy vehicles was reported. Traffic non-exhausts source, including anthropogenic dust sources such as elemental materials emitted from vehicles brake pads, tires and mechanical parts, presented different factor profiles among the several sites. Its contribution ranged between 3% (Athens rural site) and 25% (Ljubljana urban background site, though including soil dust too). A secondary aerosol source (9-34%) was identified either as secondary sulfate only, either as secondary sulfates and nitrate (when inorganic aerosol is represented rather than sulfate exclusively). Finally, two natural-origin sources were identified: Soil dust associated with elements from the earth's crust presented different profile among the sites, even in the same city. Sea salt source contribution appeared with the minimum values (1-4%) in Athens, Ljubljana and Thessaloniki cities. Lenschow approach indicated that around 40% of PM2.5 sources are coming from the regional background and 50 % of the PM2.5 composition is related with traffic. However, the main contribution of this sector was not the exhaust gases but the tyre and brake wear and resuspension of the particles, which means that even zero-emission cars would still, aggravate the air quality inside the cities.

The common and simultaneous sampling and analysis procedure in ICARUS campaigns, offered a prospect of a harmonized source apportionment approach, with the scope of identifying the similarities and differences of PM2.5 source chemical fingerprints across the cities and sampling sites. Traffic, biomass burning and fuel oil combustion are the prevailing sources for PM2.5 measured in ICARUS cities.

Acknowledgement

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Keywords: PMF, source apportionment, PM2.5

ID 159 -PAHs in fine particulate matter of six European cities: seasonal and spatial variations and implications for human health

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Polycyclic aromatic hydrocarbons (PAHs) are carcinogen compounds mainly emitted in urban areas by anthropogenic sources (i.e. traffic, domestic heating, biomass burning). In air, they are partly carried by particulate matter. The aim of this study is to provide novel atmospheric data on PAHs at a traffic, urban background and rural sites in winter and summer across European cities. Six cities involved in the project ICARUS were chosen. The seasonal and spatial variations as well as the implications for human health were investigated.

In this study, 24-h air samples of fine particles (i.e. PM2.5) were collected using an active air sampler and quartz fibre filters for 30 days in winter and summer at a traffic, an urban background and a rural site at/near Athens, Brno, Ljubljana, Madrid, Stuttgart and Thessaloniki. The filters were extracted and analyzed by means of gas chromatography coupled to mass spectrometry.

PAH levels were significantly higher in winter compared to summer in all cities investigated. These seasonal variations can be attributed to increased sources such as domestic heating or higher cold-start emissions from traffic, but also lower atmospheric boundary layer and higher gas-to-particle conversion and, probably, longer atmospheric lifetimes in winter. Nitro- and oxy-PAHs, which were also analysed in the samples from Brno and Ljubljana, showed similar seasonal variations.

Concerning the spatial distributions, the winter PAH concentrations found at Brno in central Europe were the highest. In terms of variability within the city, large differences were found among the cities. For example, in Brno, the highest PAH levels were found at the traffic site while the lowest were found at the rural site for both seasons, highlighting that traffic is the most important PAH source within the city. On the other hand, in Athens, the highest PAH levels in winter were found at the rural site, which could be due to the increase in the usage of wood combustion for domestic heating in rural areas of Greece since the economic crisis. In Ljubljana, no significant differences in the PAH concentrations were found between the traffic and the urban background sites which suggest that traffic is not controlling the PAH levels within the city. In winter, it was found that traffic controlled the nitro-PAH levels in Brno and Ljubljana but not those of oxy-PAHs.

For each of the sites involved, human health risks resulting from outdoor workday inhalation exposure will be evaluated with respect to the risk of developing cancer.

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Keywords: PAHs, urban air, human health, traffic

ID 242 - NPAHs and OPAHs in the atmosphere of two central European cities: seasonality, urban-to-background gradients and gas-to-particle partitioning

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Nitrated and Oxygenated polycyclic aromatic hydrocarbons (NPAHs and OPAHs) are emitted by anthropogenic and natural sources. They can also be secondarily formed in the atmosphere via oxidative reactions.

The aim of this study is to provide novel atmospheric data on NPAHs and OPAHs at each a traffic (T), an urban background (U) and a rural (R) site collected in winter and summer 2017 at/near Brno, Czech Republic and Ljubljana, Slovenia. The seasonal and spatial variations as well as the gas-particle partitioning of these compounds were also investigated.

Unlike 11 OPAHs which were all consistently detected, only 9 out of the 18 targeted NPAHs were consistently found in the air samples. The total (gas and particulate) concentrations of Σ9NPAHs at the three Brno sites were ranging from 7.3 pg m-3 to 2888 pg m-3. The particulate concentrations of NPAHs measured at all sites were ranging from 0.01 pg m-3 to 3008 pg m-3. OPAHs exhibited higher atmospheric levels with total and particulate concentrations ranging from 176 pg m-3 to 45053 pg m-3 and 1.7 pg m-3 to 31193 pg m-3, respectively.

Significant seasonal variations were observed for all NPAHs and OPAHs. Indeed, the winter-to-summer ratios of the particulate concentrations across all sites were 4.2-67.7 for Σ9NPAHs and 3.7-101 for Σ11OPAHs.

The particulate mass fraction of NPAHs and OPAHs seemed to follow vapour pressure. Higher particulate fractions were observed at the traffic site compared to the urban background or rural sites for some NPAHs and OPAHs.

In winter, a strong traffic to rural gradient of NPAH concentrations was observed in the Brno area. Indeed, the T/UB and T/R ratios were 3.3 and 12.2, respectively. In summer, the corresponding figures were 0.7 and 4.8 suggesting that the secondary NPAH source (photochemistry) was more significant at the urban background site (advection of

photochemically aged pollution). At Ljubljana, the T/UB ratios were 2.5 and 22.5 in winter and summer, respectively. For OPAHs, the T/UB and T/R ratios of total Σ11OPAH concentrations in Brno were 0.8 and 3.1 in winter and 0.2 and 1.7 in summer, respectively. At Ljubljana, the T/UB ratios of the particulate concentrations of Σ11OPAH were 0.9 in winter and 3.3 in summer.

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Keywords: PAH derivatives, seasonal variations, spatial variations, gas-to-particle partitioning

ID 266 - PM exposure using portable sensor data and human respiratory tract deposition modelling

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The aim of the study was to present the results of a personal exposure assessment methodology, which involved a personal sensor campaign, aiming to refine PM exposure using low-cost portable sensor data, exposure and human respiratory tract deposition modelling. A custom-made monitoring device was developed for measuring 3 fractions of PM (1, 2.5 and 10 μm), enabling direct assessment of personal exposure. The device is based on an Arduino microcontroller where small sensor-modules are connected. Sensors' performance was improved using a thorough assessment in which not only the hardware but also the information emerging from the sensors' temporal resolution was evaluated using efficient statistical and machine learning methods. In this sense, integration of sensor data with advanced exposure models allows us to significantly differentiate the actual intake to PM among individuals, at levels that are not conceived based on the spatial distribution of air quality monitoring, or among people of different age and activity patterns. In addition, participants wore a physical activity wristband (Garmin Vivosmart 3) that records steps, distance, type of activity, heartbeat and sleeping patterns. Finally, participant positions were recorded using a GPS sensor, integrated into the PM sensors. After validation, the sensors were used to capture daily variability of PM exposure for the participants.

Exposure was further refined by estimating inhalation adjusted intake rate, as well as PM deposition across human respiratory tract (HRT) using the Multiple Path Particle Deposition (MPPD) model. The above methodology was applied in the personal sensors campaign of the HORIZON2020 EU Project ICARUS, where exposure and intake to PM of almost 100 individuals was monitored. The integrated methodology outlined above, allowed us to significantly differentiate the actual intake of the participants, highlighting larger differences than the ones attributed to the spatial differentiation of the fixed station air pollution (difference of ambient PM levels of 50% were translated in intake differences up to 110%). These differences are the result of the differences in PM size fractions that are captured by the sensors and the capability of the HRT model to translate the differences in PM size distribution accounting for the differences in physiology among the participants, finally reflected in intake estimates. Overall, the combination of low-cost sensor technology combined with the proper modelling methods has indeed the potential to revolutionise the field of environmental, exposure and health monitoring, providing high-density spatiotemporal information at the individual level. These devices might not necessarily be apt to regulatory monitoring; however, they can capture variability and exposure differences between different regions and population groups, providing a better understanding of the interactions between environment and human health. This is a very important element for supporting targeted interventions for reducing exposure

of vulnerable groups, as well as towards the implementation of precision prevention strategies.

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Keywords: particulate matter, low-cost sensors, intake, human respiratory tract deposition

ID 157 Future trends on green and healthy cities. The Madrid (Spain) case

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Summary
This study aimed at providing a methodological framework to incorporate views on green, smart and healthy cities into a single long-term vision by 2050. The Madrid City has served as a case study within the EU ICARUS project. The main outcomes can being summarized in a single vision called "slow city".

Introduction
According to WHO (2016), poor air quality is one of the main environmental risks because of its impact on human health and the authorities are aware of it. Nowadays the main reaction to cope with this problem is to set up air quality plans, policies and actions to reduce the levels of atmospheric pollutants and improve the air quality especially in urban areas. However, the lack of a future vision constrains the implementation of long-term policies towards healthier, smarter and more sustainable cities. Therefore, future visions developed by professionals in collaboration with key stakeholders (public health, urbanism mobility, etc.) can be an excellent tool that should be considered to the aforementioned air quality plans, thus making a success on the medium and long-term future of cities.

Methodology and Results
To elaborate a future vision, a dynamic collaborative process has been followed. This was a bottom-up process, in which experts from different sectors and policy-makers determined future green and healthy visions based on a dynamic implementation of the collaborative process. The methodological process was structured into four sequential phases, which evolved from preliminary literature reviews to identify potential future trends, semi-structure interviews with experts to gather their views and participatory workshops to elaborate longer term narratives visions where refinement of collective views could take place. At the final stage, a multi-criteria analysis (MCA) was carried out to select the final future narrative.

In the Madrid city case, the participatory workshop brought to the elaboration of four partial narratives: (i), "The car paradise", based on a scenario where private car will predominate and the multifunctional level of the city will be very high; (ii) " The long distance city", for those scenarios in which the multifunctional level of the city will be very low and private vehicles will predominate; (iii) "The public transport paradise" for the scenario in which public transport will predominate, but larger distances should be covered due to the low multifunctional level of the city; (iv) "the slow city" for that scenario in which public transport will predominate and the multifunctional level of the city will be very high. To select a final future narrative, an MCA was carried out. The MCA was based on a questionnaire design to analyse the narratives based on which one generate more positive impacts for environment, economics and society, and where local policy makers were asked to participate. In particular, the Analytic Hierarchy Process (AHP) developed by Saaty (2013) was used to derive ratio scales from both discrete and continuous paired comparisons of sustainability impact categories. These comparisons were taken from a nine-point scale, which reflected the relative strength of preferences and feelings of policy-makers on the likelihood that specific impacts from each category can be generated by the four narratives visions. During the process, four pair-wise matrices (environmental, social, economic, and global matrix) were obtained for each future vision and transformed into priority vectors. The combination of priority vectors provided weights to rank the impacts expected to be generated by each vision. Finally, the visions with the highest weight were selected. As summary, the long-distance city generated the worst impact among all the analysed categories and resulting in last rank position. The Public transport paradise and the car paradise showed a better impact, 0.10 and 0.28 respectively, and were ranked into the third and second position. The Slow city vision obtained the best impact record among all categories (0.66-0.54). This future vision was the preferred one by the stakeholders for Madrid 2050.

Conclusions

This study selected the so-called "slow city" scenario for Madrid 2050. This model stands for a multifunctional city where the activities and employments are in nearby areas so, all the daily needs (shopping, leisure, exercise, mobility, etc.) can be satisfied due to the household/office proximity.

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Keywords: smart green and healthy cities, future trends, Madrid, narratives, slow city

ID 138 - A Decision Support System (DSS) for integrated climate forcing and air pollution reduction and in European Cities

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Air quality is a very important factor that has a severe impact to the health of millions of people around the globe. Together with climate change, they play a most important role to the quality of life and the expectance of the population, with those residing in or close to urban environments being the most affected. There is growing recognition that a comprehensive and combined analysis of air pollution and climate change could reveal important synergies of emission control measures which could be of high policy relevance. Insight into the multiple benefits of control measures could make emission controls economically more viable, both in industrialized and developing countries. While scientific understanding on many individual aspects of air pollution and climate change has considerably increased in the last years, little attention has been paid to a holistic analysis of the interactions between both problems. In this context, the ICARUS Decision Support System (DSS) is mainly intended to assist policy makers of all levels of administration, NGOs and research institutes whose activities relate to air quality and climate forcing. Policy makers of municipal, regional and national level will be able to use the DSS in order to design and simulate the impact of potential measures. The ICARUS DSS provides policy and measures impact estimations at many levels, namely: emissions, pollutants concentration, population exposure, health impact, monetary evaluation and at three temporal levels, 2015, 2020 and 2030. To this end, the DSS implements the models developed in the ICARUS research project, taking into consideration the particularities of each region, including population activities and habits, based on their socioeconomic status. Special focus is given to the exploitation of data of several data types and formats, originating by numerous different sources, such as meteorological and concentration measurement stations, smartphone and wearable sensors. Particular attention has been paid to the analysis of the spatial and temporal relations between the data types involved. Datasets are provided in a standard format, compliant with the INSPIRE Directive.

The policy makers will be able to select a policy from a set of predefined scenarios and proceed to select or draw an area of interest, on which the different impacts will be calculated by the DSS. Apart from selecting among predefined policy scenarios, the policy makers will be also able to import their own data for their jurisdictions and to also define their own custom policies. An essential feature of the DSS is the ability to evaluate the policy impacts while it is being applied, by importing air quality data that they might be in possession of and comparing them to the estimates. Finally, NGOs and researchers may use the DSS to retrieve data and facilitate their research.

Great emphasis has been put into the usability, security, interoperability and scalability of the DSS, which is accessible through an open-source WebGIS infrastructure, integrating all project information, enabling users to manage and process spatial data and to effectively visualize the results of spatially resolved models. This will enable access from any computer through a browser, without requiring installation.

The project methodology was applied in nine European cities of variable size starting from relatively small (Basel, Brno, Ljubljana, Roskilde) to mid-size (Stuttgart, Thessaloniki) to large cities (Athens, Milan and Madrid). They were selected carefully to represent the mix of urban settings around Europe and cover the whole spectrum of "green urban management".

ICARUS aims at the improvement of life quality and public health, as well as environmental risk reduction. It proposes an innovative system to assess and monitor AQ and adverse health effects of exposure to poor AQ in an integrated, cost-effective and dependable way, using to the maximum current and near-future capabilities of the environmental monitoring and telematics infrastructure. The ICARUS DSS deployment and application in several cities across Europe is expected to have a positive impact on local society and the economy contributing to lower the health costs associated to environmental burden. In this regard, one of the expected key results is the identification of strategies to improve air quality, cope with climate change and lower health costs.

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Keywords: Air quality, Climate change, Emissions, Health impact, Decision Support System

ID 144 - Real time personal exposure assessment using low-cost sensors

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A comprehensive personal exposure study was conducted in seven European cities, in frame of ICARUS Horizon2020 project. The investigation assessed the exposure of volunteers in different microenvironments, including both wearable sensors to track personal exposure to environmental stressors and activity levels and static sensors to monitor Indoor Air Quality (IAQ) inside their residences. This study aims to develop a high spatial and temporal resolution population exposure estimation methodology, based on static/portable, low-cost, advanced technologies.

Concerning the Athens campaign, 100 individuals (34 households) living across the Attica region were participated. Volunteers coming from a wide range of age and socio-demographic status were recruited. The sampling period for each household was seven days, including a weekend, while the measurements in each residence took place both in summer and winter, in order for seasonal variation to be examined. Personal monitoring included: a physical activity sensor tracking steps, floors climbed, intensity minutes and heart rate on continuous basis and a custom-made monitoring device measuring PM concentrations. In order to assess IAQ in participants' households, an additional sensor was placed in their living rooms to measure temperature, relative humidity, carbon dioxide (CO2), PM2.5, nitrogen dioxide (NO2), ozone (O3) and total volatile organic compounds (TVOCs). Participants were asked to fill out a questionnaire to gather information about the characteristics of their household. They were also asked to fill in a time activity diary during the campaign, giving information about the kind of activities they carried out and the places they visited. Preliminary results show a significant range of the measured pollutants among the studied households. In particular, PM2.5 average concentration inside the residences ranged between 6.7- 63.5 μg/m3 during the winter and 6.8-139 μg/m3 during the summer period. As for the personal exposure monitoring, the highest PM values were observed in public means of transport and inside crowded environments, such as restaurants and cafes. TVOC concentrations were highly variable both between the houses and within individual residences, while higher concentrations were recorded during the summer period with respect to the winter. As for the CO2 concentrations, exceeded the ASHRAE 62.1-2016 recommendation of 1000 ppm in several houses, especially during the summer campaign.

Research results and methodology of the present study not only provide a reference for future personal exposure studies, but also can be used by policy makers to design control policies.

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Keywords: personal exposure, PM, IAQ, sensors

ID 163 - Personal exposure to air pollution: the Milan sensor campaign in ICARUS project

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Summary
This study aims at presenting the results of collection of multi-sensor data for personal exposure monitoring carried out in Milan (Italy) in 2019. About 100 individuals from all ages and all sociodemographic groups, with a focus on vulnerable groups of population (e.g. children and elderly), have been recruited for the implementation of the study. The process includes both at home and personal monitoring for 7 days, in both summer and winter periods. The types of information collected are based on: exposure monitoring devices, physical activity tracker, questionnaires and time activity diaries. This work is part of a comprehensive study carried out in other 8 European cities in the framework of the ICARUS project.

Introduction
ICARUS is a 4-year EU-H2020 project focusing on research areas related to the climate and the environment and their interactions with health and wellbeing. The ICARUS project's main objective is to develop integrated tools and strategies for urban impact assessment in support of air quality and climate change governance in EU Member States leading to the design and implementation of appropriate strategies to improve the air quality (AQ) and reduce the carbon footprint in European cities. The main objectives of the campaigns were to: collect data on external environmental exposure and exposure determinants by combining location, activity and air pollution data in different microenvironments; demonstrate feasibility of using new sensors and mobile technologies in collecting exposure data; analyse and compare exposure data in several different European cities; use data to parameterize and/or validate simulation models (Agent Based Models).

Methodology and Results
The winter campaign was carried out from January 10th to January 30th 2019, with 89 participants from 39 households while the summer one from June 12th to July 2nd 2019, with

65 participants from 30 households, leading to a total of 42 different households and 97 participants. *Participant recruitment*: thanks to the collaboration of the key local stakeholders such us the Municipality of Milan we issued a volunteer search advertisement in July 2018 on Milan Municipality's website asking interested people to fill in an online survey to express their interest to participate in the campaigns and to provide some information on the age, gender, location of household and workplace so as to have an optimal distribution of participants covering as much as possible the whole municipality territory as well as different age and gender combinations. *Sensors used*: (a) Physical activity wristband (Garmin Vivosmart 3) for steps, distance, floors climbed, type of activity, heart rate, sleep time; (b) Personal PM sensor for PM1, PM2.5, PM10, temperature, humidity, GPS; (c) uHoo static sensor (indoor) for CO, CO2, VOCs, PM2.5, O3, NO2, air pressure, temperature, humidity; (d) Silicone wristband for organic chemicals (passive sampler).
In addition to these devices, we also used 3 different questionnaires that allowed us to better understand the participants' habits and their personal and living conditions: a Time Activity Diary (TAD) to collect the activities carried out (both outdoor and indoor) and house conditions (open windows, candles, A/C on) on hourly basis; two surveys, the first focusing on household additional characteristics and the second for the participants to gather the daily habits (transports, sports, health status). Data from these questionnaires were used to derive socio-economic status (SES) of participants and to associate exposure to pollutants with this variable and other specific features. Results of measurements has been collated, analyzed and finally distributed to all participants in targeted reports for each participant. The latter included air quality levels (CO2, NO2, VOCs) in the household reported as heatmaps showing deviation in hourly averages form the overall averages, while individual measurements were reported with one minutes time resolution to emphasize variations in concentrations over time plotted against average daily limits as defined by WHO Air Quality Guideline; finally we reported values of exposure to PM for various microenvironments and different activities. The summary of the data for the whole campaign, and comparisons between households and participants data where possible, were reported as well: indoor air quality in each household along with the meteorological conditions measured; patterns of indoor pollution levels for different households in the same days; personal exposure to PM data correlation with SES variables and geographical position of households; exposure patterns for different participants in the same households. User experience and feedback as reported by participants has been collected as well.

Conclusions

The next plan is to use the sensor campaign data to validate ABM for modelling exposure in the city, in order to create a useful tool for the Municipality, to better understand the indoor and outdoor exposure patterns for each "agent" representing a specific group in the population with different features and daily habits. The results of Milan sensor campaign, together with the other ICARUS cities involved within the framework of the project will contribute to inform and nurture environment-conscious citizens, to raise citizens and authorities awareness about health impact of air pollution and motivate citizens to adopt alternative behaviours, to develop visions of smart, green & healthy cities with minimum environmental and health impact and to propose win-win solutions for climate change mitigation and air pollution reduction.

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