Integrated Climate forcing and Air pollution Reduction in Urban Systems

(ICARUS)

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Introduction to ICARUS

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 abatement strategies to improve the air quality and reduce the carbon footprint in European cities. We will develop detailed policies and measures for air pollution and climate control for the short and medium term (until ca. 2030). For the long term perspective (2050 and beyond) we will develop visions of green cities and explore pathways on how to start realizing these visions. The specific project objectives are to quantitatively assess the impact of current and alternative national and local policies on reducing greenhouse gas (GHG) emissions and improving air quality through a full chain approach and evaluate the future public health and well-being impacts of these policies in European cities.

For each policy analysed the following effects/impacts will be evaluated:

- Change in emissions of air pollutants including life cycle emissions in/outside cities for selected activities.
- Change in emissions of greenhouse gases including life cycle emissions in/outside city (thus changes in the carbon footprint caused by changes in sectorial activities).
- Changes in ambient concentration of air pollutants and greenhouse gases. Changes in the exposure to air pollutants taking into account important indoor sources.
- Changes in the associated impacts on human health.
- Societal and economic impacts, including costs for the emission source operator and for other actors of society, including health impacts, time losses or gains and wider impacts.
- Demands regarding implementation of the policies with the consideration of indirect effects (e.g. changes in urbanization and land-use in the cities which support physical activity by extending cycling infrastructure and changes in modal split).
- evaluate (using source apportionment and atmospheric modelling) the current contributions of the different pollution sources linked to urban activities including heat and power use in the urban building stock, urban traffic and transportation needs, energy production, industrial activities including energy production, agriculture and trans-boundary pollution with respect to GHG-emissions, air quality loading, public health and well-being of the population.
- propose measures of technological (i.e. measures that will lead to a reduction of emissions at the source) and non-technological (i.e. measures that induce behavioural changes) nature to reduce both carbon footprint and air quality burden (win-win solutions). Techno-economic analysis of possible scenarios for the introduction of such measures will result in the definition of cost-effective environmental and climate protection and air quality management plans adapted to the specific needs of different EU cities and regions. The effect of these measures will be evaluated jointly taking into account the socioeconomic drivers related to the existing and projected scenarios.
- develop visions of green cities with clean air, close to zero or negative carbon footprint and maximal wellbeing, develop a pathway for the realisation of these visions in the next 50 years and propose first steps down that road in the form of a concrete plan towards achieving these visions in the participating cities.
- raise awareness of the citizens about the impacts on public health and the climate causes by their activities or with changes in their activities.

The results of the policy analyses will allow us to determine the most sustainable GHG mitigation and air quality (AQ) improvement strategies. The latter will be proposed to the authorities competent for atmospheric pollution and climate protection management and to the main industrial end-users as guidance for decision making that would lead towards maximizing the net public health and wellbeing benefits while taking into consideration the costs associated with air pollution and climate change in the EU.

We will employ state-of-the-art technologies for fusing the necessary environmental and ancillary information to allow for cost-effective air pollution monitoring and assessment. An **integrated approach** will be used for air pollution monitoring combining ground-based measurements, atmospheric transport and chemical transformation modelling and air pollution indicators derived from satellite, airborne and personal remote sensing.

ICARUS will develop a vision of a future green city: a visionary model that will seek to minimize environmental, climate and health impacts in the participating cities. To this aim we will develop a transition pathway, which will demonstrate how current cities in Europe could be transformed towards green cities within the next 50 years.

To raise citizen awareness regarding the impacts of their activities on air pollution and climate forcing and increase societal acceptance of emission reduction policies, a web- and smartphone/tablet-based tool will be health impacts of their actions/consumer choices. They could then explore individually how downstream impacts change from commensurate change in their behaviour/activities or monitor the overall social responsibility in their area/neighbourhood and how it affects their quality of life.

Research in ICARUS will be user-driven, scientifically innovative and it is designed to engage local communities in the participating cities. Starting from the perspective of meeting policy makers and stakeholders needs has profound analytical and methodological implications. The ICARUS project will embrace the current perceptions and vulnerabilities of decision-makers, while also embedding interaction between researchers and stakeholders in all aspects of research, implementation and dissemination. City partners will have a strong role in the project activities. They would, together with the scientific partners, analyse the effects of the policies already implemented in the cities, estimate the effect of implementing further measures and use results to set up a strategy for their city in the longer time-frames.

ICARUS consortium

The ICARUS Consortium is made up of 18 Partner Institutions from 9 European countries as shown in Figure 1, all with multidisciplinary expertise and experience in intersecting and complimentary research in research areas related to the climate and the environment and their interactions with health and wellbeing. The high scientific quality of the ICARUS team is based on the extensive and long-term experience of the partners, which include leading scientists and risk health research institutes in Europe.

Figure 1. ICARUS Participants geographical distribution

A balanced consortium was chosen to assemble all knowledge, research facilities, models and experiences together to do the research, needed to meet the objectives of ICARUS. The key research groups are distributed across many parts of Europe, bringing together the necessary know-how in the necessary fields including atmospheric dynamics, atmospheric chemistry, urban, regional and global scale modelling, emissions and ground-based, laboratory, aircraft and satellite measurement groups. The Consortium is committed to producing high quality inter/multi-disciplinary relevant research which addresses the opportunities and benefits as well as risks of these interactions, particularly around urban environmental projects. ICARUS builds upon and complements the existing interdisciplinary skills and research activities of the research team from a range of current and prior research efforts. The consortium is made up of 12 academic and research institutes (which are in close co-operation with the respective city authorities), 5 SMEs (of which 1 is the development agency of the city of Athens) and 1 European city authority. The academic partners will build the foundations of the project, SMEs will transform it to user-friendly tools and methods and finally the 9 European cities which are joining the project will testbed and prove the project results. ICARUS is a very well balanced consortium, with emphasis on the quality of the project outcome and the validation of the results by real-life entities (cities and citizens).

Participating SMEs not only help bridge the gap between the academic world and citizens; they will further exploit the delivered platform and guarantee the use of the project results for the years to come.

The overall coordination and administration (including interactions with the Advisory Board and with the EC Project Officer) of ICARUS will be led by the Project Coordinator (AUTH), Professor Dimosthenis Sarigiannis (PC, Project Coordinator), and his team. Professor Dimosthenis Sarigiannis is a Chemical Engineer with over 20 years of experience and expertise in environmental and occupational exposures and human health at the Department of Chemical Engineering of the Aristotle University of Thessaloniki (Greece) and Associate Professor of Environmental Health Engineering at the Institute for Advanced Study (IUSS) of Pavia (Italy), adjunct Professor at the Master‟s Program on Toxicology and Environmental Risk at the Medical School of the University of Pavia, and Senior Scientist at the Chemical Assessment and Testing Unit of the Institute for Health and Consumer Protection at the European Commission’s Joint Research Centre (currently on leave). He is member of the international forum for evidence-based toxicology, of the scientific committee for chronic risks of INERIS. He has coordinated several EU-funded research projects on environment and health such as SMAQ, ICAROS and ICAROSNET, TAGS and INTERA and he has been in the management team to the IPs HEIMTSA, 2-FUN, NO MIRACLE, HENVINET, CAIR4HEALTH, HEREPLUS, and GENESIS. Currently, he is leading the two largest multi-center projects on the European exposome initiative, HEALS and CROME. Furthermore, he currently lead a project on integrated external and internal exposure assessment (INTEGRA) with funding from the European Chemical Industry Association’s long-range research initiative. He is co-PI in two large-scale European projects on: (a) understanding the mechanisms of exposure and health impact of transport-related particulate matter (TRANSPHORM) and (b) assessing the health impact of local climate change policies in Europe and China funded by the European Commission (URGENCHE); he is co-PI and member of the management committee of an EU-wide network on industrial contaminated sites and human health. He is part of the global chemical risk assessment network of the WHO and advisor of WHO Europe (Center on Environment and Health) on endocrine disruptors exposure and health impacts and on human biomonitoring.

The sheer amount of leading-edge scientific knowledge and innovative technologies needed to research and develop the different components foreseen in the ICARUS project require a cross-border and interdisciplinary approach. For this reason the ICARUS consortium is composed of different pioneers in the various fields involved in the project, eager to take on the multi-disciplinary challenges of managing, preserving and computing with big, cross-domain data in environment and health sciences. The concrete responsibilities and individual capacities of each beneficiary are provided in Section 4 of the proposal. All key areas of scientific and technical innovation within the project are covered by one or more technical partners, thus guaranteeing a good transfer of knowledge from anticipated innovation activities. The consortium will collaborate together in all phases foreseen in the project, towards fulfilling the ambitions envisioned in ICARUS.

ICARUS workplan

Workflow structure, concept and approach

ICARUS policies are defined as the use of eco-political instruments (command and control policies, taxes, etc.) to enforce environmental protection by public authorities, while the induced measures are reactions of operators of emission sources when confronted with policies. The bundle of policies and related measures are called options. Policies include urban policies as well as regional/EU wide policies, as long as the latter have a considerable effect on air pollution in cities (e.g. formation of SIA-secondary inorganic aerosol). The measures analysed will include technical (i.e. measures that change emission factors such as use of filters, change of technical process with same output) and non-technical measures that change behaviour/decisions, e.g. use of a bicycle instead of a private car or reduction of room temperature. Estimation of the marginal change of ambient concentration caused by a change in emissions is a critical element of the impact pathway. The usual approach, i.e. using atmospheric models, gives very poor results for key pollutants such as PM2.5 and NO_2. Thus, possibilities to improve source apportionment methods and establish a relationship between emission and concentration variation will be explored. Input will also come from existing monitoring, including ground based stations and satellites, as well as new measurements taken with ground and airborne sensors in the participating cities. Based on this data new **data fusion** methods using information theory and artificial intelligence will be developed to describe the link between emissions and concentrations. Instead of using unrealistic general equilibrium models to simulate societal responses to environmental policies we will make use of **agent-based modelling** to capture the interactions of several population subgroups, industries and service providers in response to the policies considered in the project. Thus social and cultural factors, socio-economic status (SES) and societal dynamics will be explicitly taken into account to assess overall policy impact. Agent based modelling will be also used to evaluate decisions/behavioural changes of the polluters.

Overall, the links among the various methodological elements and the respective WPs of ICARUS, are graphically illustrated in Figure 2.

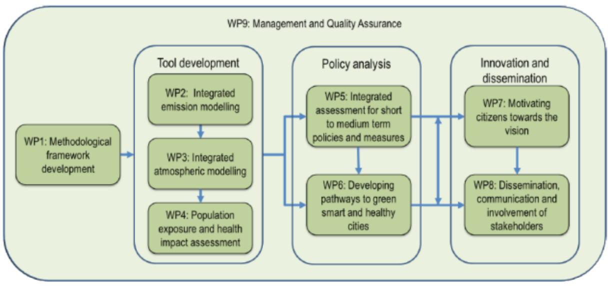


Figure 2. Methodological framework development (Leader: AUTH)

Participating cities

The project methodology will be applied in nine European cities of variable size starting from relatively small (Basel, Brno, Ljubljana) to mid-size (Stuttgart, Bristol, Thessaloniki) to large cities (Athens, Milan and Madrid).

They have been selected carefully to represent the mix of urban settings around Europe and cover the whole spectrum of “green urban management”. Rich large metropolitan conglomerates, which anyway have enough own resources to establish environmental plans, have been avoided in order to ensure that the ICARUS approach captures variable, yet realistic intervention scenarios that are relevant for the vast majority (> 80%) of the urban population in the EU. The selection was made also on geo-demographic criteria so that the variable socio-economic dynamics across the EU can be clearly captured and taken into account.

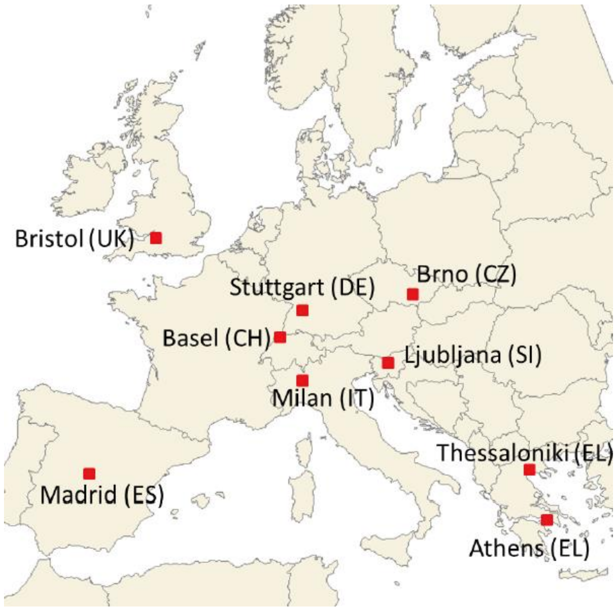


Figure 3. Cities participating in the project

The cities involved cover a wide range of environmental problems as well as of several countermeasures to reduce air pollution and carbon footprint already adopted or planned. Stuttgart, Milan, Athens and Thessaloniki have severe air pollution problems due to high emissions mainly from industrial, transport and domestic heating sectors in some cases worsened by unfavourable climate characteristics (i.e. Milan and Stuttgart). Other cities suffered mainly in the past from heavy air pollution (i.e. Brno and Ljubljana), which in recent years has been partly faced due to effective policy decisions. All cities involved have already adopted a number of technical and non-technical measures to reduce air pollution and carbon footprint which ranges from energy use reduction by retrofitting to enhance carbon-neutral sources of energy generation and from new low carbon transportation plan to increased energy performance of existing building. These measures have been accompanied by other non-technical measures such as widespread low speed limit in the cities, traffic restricted zones, increase of green spaces, new cycle tracks, introduction of fees for transport in restricted areas and ban on certain fuels for heating and cooling purposes. All cities have ambitious plans to bring local government and the local communities together to start implementing a new vision of green city making them appropriate to demonstrate the ICARUS methodology.

Key technological advances proposed in ICARUS

Sensors - Advancing personal and population exposure assessment

Technological advances in the recent years have produced sophisticated monitoring devices which can be carried or worn by a person during their regular daily routine allowing for personal exposure to be monitored explicitly. Smartphone apps, wireless devices and the downsizing of monitoring technologies and costs make it possible for various environmental stressors and exposure factors to be measured more easily and frequently, thus providing a more reliable “time–geography of exposure” shifting the current paradigm from a population to an individual level.

From an operational point of view personal sensors can be grouped according to the type of data they can provide: passive pollution measuring sensors which can measure the pollution levels encountered in the different locations where users spend their days, tracking location and physical activity sensors which provide information about the spatial patterns of user location and physical activity.

Direct reading monitors will help us to identify whether peak exposures are more important than average exposure values, identify specific exposure pathways that dominate in critical time windows over an individual’s lifetime, and finally build individual exposure profiles. **Combining information on individual position with spatially resolved pollution levels allows us to assign pollutant concentrations to a person as they move through different microenvironments. Moreover, information on individual physical activity as tracked by personal sensors allows the estimation of the breathing rates during different activities which in turns translated into inhaled dose.**

This highly novel and promising approach will give us access to an unprecedented amount of “individualized exposure data,” which could greatly improve our understanding of exposure and health associations but which are worthless without interpretation (e.g. human behaviour recognition). This requires statistical advances, sophisticated data mining techniques, computing power as well as a careful sharing of data sources while also maintaining privacy protections for personal data. Big data is difficult to be used with classical relational databases, desktop statistics and traditional visualization packages. What is common for big data treatment is that it is not just about storing huge amounts of data; it is the ability to mine and integrate data, extracting new knowledge from it. Appling this innovative framework to construct the individual exposome in the pilot EU-wide Exposure and Health survey (EXHES) as well as in the existing cohorts, HEALS will bring advances in this area to overcome the current limiting factors related to the analysis and the interpretation of the enormous wealth of data generated necessary to move the current approach from a population to a personalized level.

A preliminary study took place, aiming to examine the feasibility of using a series of sensors for tracking personal location and activities. Four participants in the city of Thessaloniki, Greece, wore a series of devices such as a) a temperature logger to detect changes between indoor and outdoor conditions, b) a commercially available fitness monitor to capture motion and intense of activity, c) a GPS device to track location and speed along with d) Moves, a smartphone application that enables tracking of location and activity. Additionally, a time activity diary was filled out on paper by participants for each day.

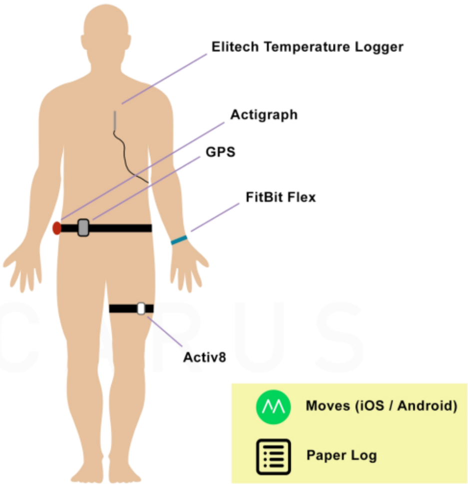


Figure 4. Overview of the personal sensors used during the preliminary trial campaign

Since location data alone does not reliably determine whether a person is indoors, outdoors or in transit, the predictive value of additional sensors data (e.g.: personal speed, personal air temperature and historical weather data) was explored using an Artificial Neural Network (ANN) model, aiming to derive to a time-activity model based *solely* on sensor data.

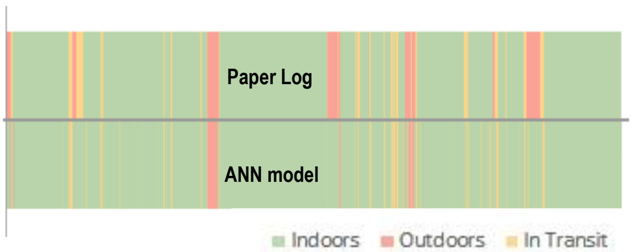


Figure 5. A visual comparison between the real location data and the predicted ones derived by the ANN model.

The independent variables that fed the ANN input layer consisted of a) personal temperature, *T*, derived from the wearable temperature sensor, b) the rate of temperature change, *dT/dt*, c) personal speed, derived from the GPS devices worn by the participants, *v*, e) the observed temperature, derived from a meteorological station located in the historical centre of Thessaloniki, T_{out}, d) and the ratio of the personal temperature to the observed one, T/T_{out}. Moreover, information on day light - whether it is day or night based on time - was transformed into a categorical variable (day or night) which was also included as input. The ANN predicted results were then compared to the real data based on time-activity log records that were filled out on paper by participants. The accuracy of the ANN predictions is close to 87%.

Using a Monte Carlo analysis, distributions of participant movement and activities - derived from the multi-sensor measurements - were extrapolated to a larger population. The final distribution of a representative sample helped us to define the way with which people are moving in space and time (what time they start/finish work/school, their speed) as well as their different types of activity (sleeping, working, resting etc.) within the boundaries of a city. This was valuable information that was then translated into moving human agents based on an Agent Based Modelling (ABM) platform.

Personal exposure assessment using portable sensors data and Agent Based Modelling (ABM).

ABM is a modelling technique that simulates the actions and interactions of autonomous software objects, the “agents”, enabling a better understanding of the behaviour of individuals and populations in social and evolutionary settings.

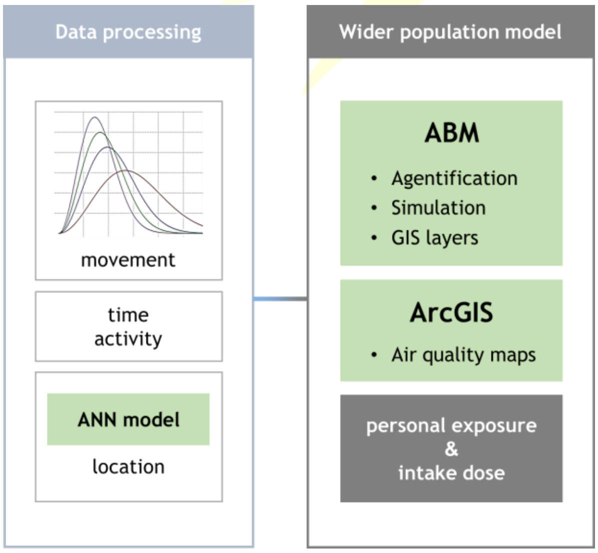


Figure 6. From sensors data to a personal exposure model.

Agents (which can be people, vehicles, roads, cities, animals, products, etc.) are programmed to react and act in their environment and to have goals that they aim to satisfy. An agent based model requires many simulations to evaluate any particular situation as it is based upon an underlying stochastic model. By storing data in a geographic information system (GIS) format and using geographically explicit ABM architecture, the trajectory of an individual participant, “human agent”, was modelled and projected on a single topographic layer.

Thessaloniki model: Using the developed ABM platform, the city of Thessaloniki (*layer 1: road network, layer 2: buildings network*) can be projected with human agents programmed to move, on a representative day, from their household to either their office or their school depending on their age. They use different means of transportation and they follow different activity patterns. The human agents’ movement and activities, derived by the coded routine, are captured as points in a GIS shapefile. Individual exposure to PM concentration is deduced via superimposing the human agent’s trajectory *(layer 3)* on daily average PM concentration maps *(layer 4)*, modelled for the same region. These maps are the outcome of data fusion from ground observations, pollutants dispersion modelling and satellite images. GIS zonal statistics can then be utilized to compute the average concentration an agent is exposed to per space and time. The high spatial resolution map allows us to calculate exposure at the level of building block. Personal exposure, expressed as inhalation-adjusted exposure to air pollutants is then evaluated by assigning pollutant concentrations to an agent based on his/her coordinates, activities and the corresponding inhalation rate.

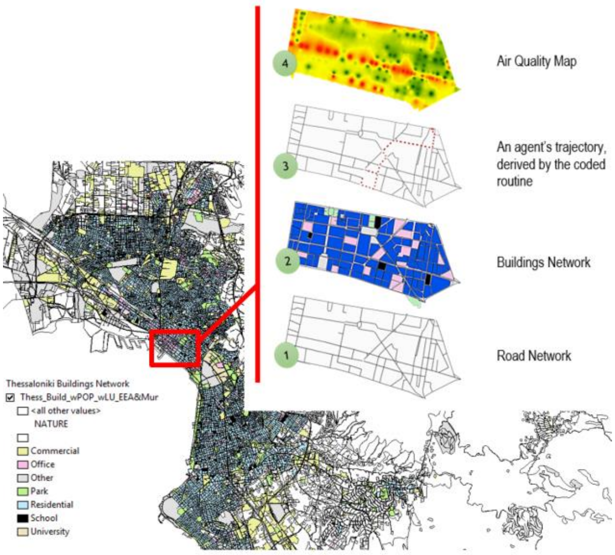


Figure 7. Exposure assessment using Agent Based Modelling (ABM).

Changes in exposure levels can be calculated for individuals and specific subgroups of population based on different spatio - temporal behaviours. ABM-generated distributions of human agents’ behavioural patterns can also work as an input into a probabilistic exposure assessment model.

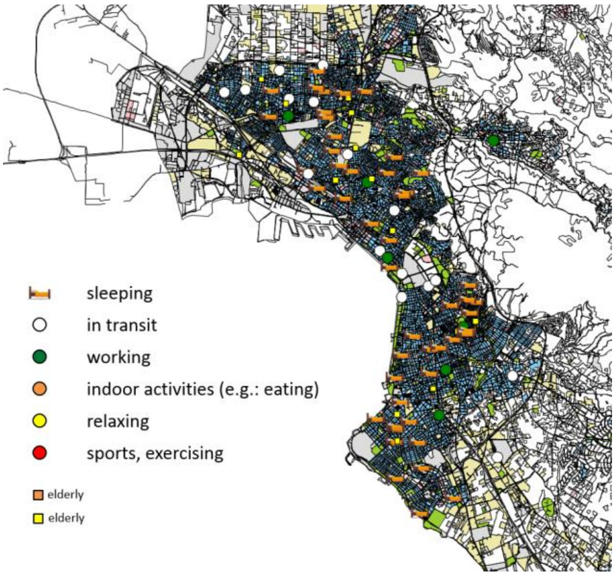
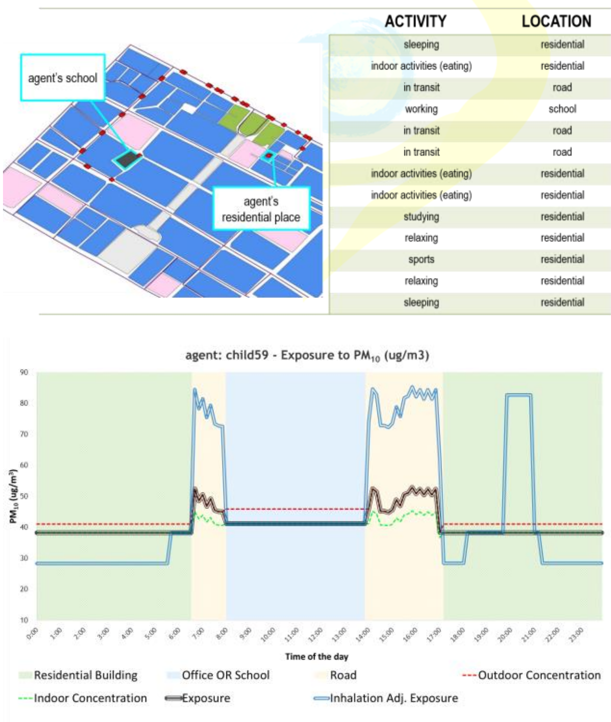


Figure 8. Moving human agents on a representative day in the city of Thessaloniki - running example of the ABM platform.

The following figures show the activity profile, exposure to PM10 (*black line)*, inhalation adjusted exposure (*blue line)* as well as intake dose of a randomly picked child agent, as derived by the model.



ACTIVITY	LOCATION
sleeping	residential
indoor activities (eating)	residential
in transit	road
working	school
in transit	road
in transit	road
indoor activities (eating)	residential
indoor activities (eating)	residential
studying	residential
relaxing	residential
sports	residential
relaxing	residential
sleeping	residential

Figure 9. Exposure to PM10 (*in black)*, inhalation adjusted exposure (*in blue)* of a randomly picked child agent, as derived by the model.

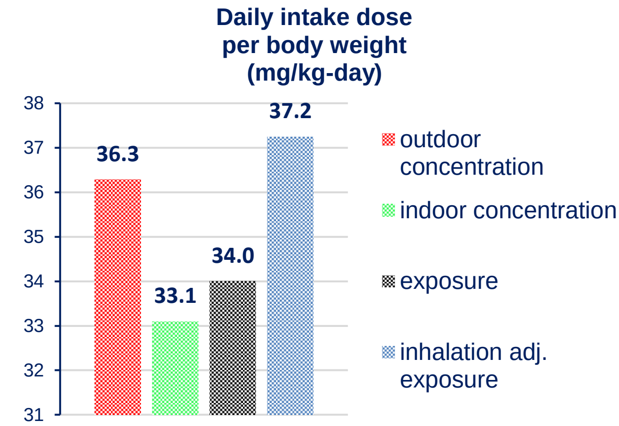


Figure 10. PM10 Daily intake dose of a randomly picked child agent.

On average, personal exposure results were between 10 and 20% more accurate than the equivalent estimate using ambient air concentration of PM as exposure proxy.

- The ABM approach brings a new way to study the complex systems, allowing to take into account the heterogeneity of the entities composing a system.
- The dynamic nature of intake dose and the identification of exposure peaks and troughs throughout the day leads to useful conclusions regarding capping exposure to high pollution levels.
- It is clear that data collected by "smart" devices can help provide more accurate exposure assessment for exposure simulation modelling and environmental health studies. The sensors investigations offer valuable information on the utility of several commercial devices as modular add-ons to exposure studies.
- Such a model would be useful for exposure assessment not only for population as a whole but most importantly, for specific vulnerable subgroups, such as children, the elderly and people with low socioeconomic status, taking into account their different activity patterns, consumer behaviors and other lifestyles.

This study represents the first step towards improving the calculation process of population exposure to environmental substances so that we would be able to draw better conclusions on the association between environment and health.

Advanced satellite data fusion - PM estimation and related health impact assessment

The method developed in the frame of the EU-funded projects ICAROS, ICAROSNET, SMAQ and HEREPLUS dealt with the development of a novel methodology which integrates ground-based measurements, atmospheric transport modeling results and satellite-derived information through a range of data fusion techniques to provide a comprehensive estimate of tropospheric pollution from particulate matter at the urban to regional scales. Linking the latter with epidemiological data and activity modeling, allows reckoning the geo-referenced health risk to population form fine and ultra-fine PM.

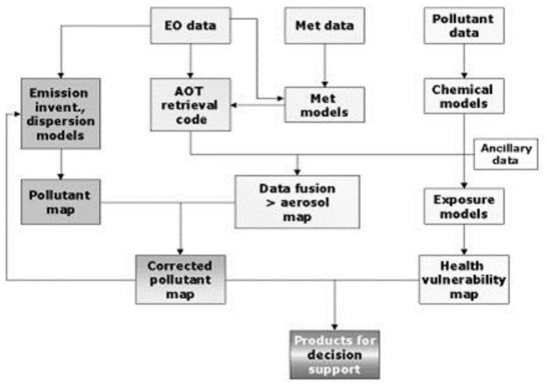


Figure 11. Conceptual representation of the advanced satellite data fusion system

Earth observation (EO) from satellite, in fact, may provide an additional information layer through the calculation of suitable air pollution indicators, such as atmospheric turbidity as measured by the atmospheric aerosol optical thickness (AOT). This calculation is based on the knowledge that the optical atmospheric effects of pollution on High Resolution Sensors (HRS) EO data are more pronounced in certain spectral bands than in others; this permits a first delineation of polluted areas and localization of emission sources, through computer assisted photo-interpretation of satellite imagery.

More specifically, fusing processed EO HRS data such as the ones obtained from the LANDSAT TM and the SPOT family, with ground-based measurement data, atmospheric dispersion modelling results and meteorological information (mixing height, relative humidity) can provide full spatial coverage of the area of interest at very high spatial resolution (up to 10 by 10 meters) allowing quantitative assessment of the PM pollution levels also at street level covering a domain as large as 80-100 x 80-100 km^2.

The methodology we developed was applied in Athens and the region of Western Macedonia (Greece), Munich (Germany), Rome and Lombardy (Italy) and Budapest (Hungary) covering a broad spectrum of climatic conditions, pollution patterns and land use types. The results converge towards a theoretical model that explains the link between the optical signal retrieved by satellites sensors and the mass concentration of tropospheric aerosol.

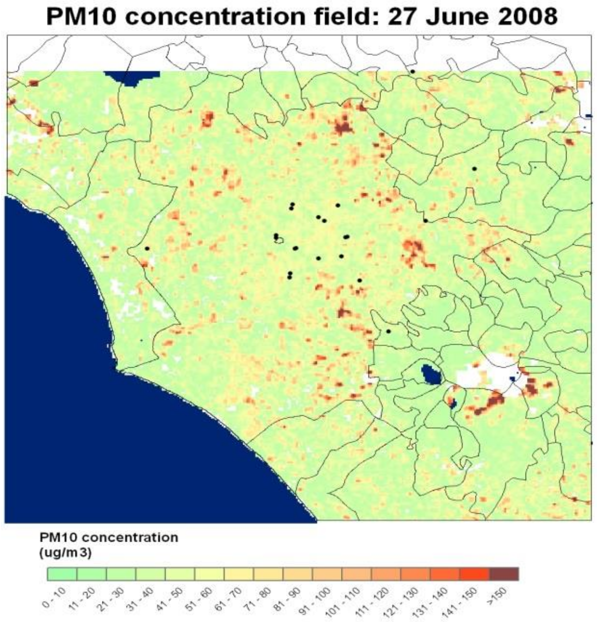


Figure 12. Application of the fusion system in Rome

Results showed that the computational model developed allows highly accurate estimates of particulate pollution and their health effects at high spatial resolution providing a valid approach for overcoming the pitfalls of current atmospheric observation systems and allowing to reduce the overall error to levels lower than the current atmospheric models as well as the pollutant concentration maps produced by spatial interpolation of measurements from the ground.

This allows the accurate spatial identification of hot-spot areas where air quality and public health managers need to concentrate their efforts.

Moreover, the derivation of high resolution estimates of PM mass concentration can support the optimization of air quality monitoring networks; using EO data as input relieves the monitoring from its most significant bias: the location of the monitoring stations, which are used to give the basic information on the spatial distribution of particulate pollution.

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Urban waste management as a key sector towards green cities

Life cycle analysis of municipal waste management - Industrial symbiosis options for reduced ecological footprint

Municipal solid waste (MSW) management is nowadays one of the biggest problems in both developed and developing countries. Prevention, recycling, treatment and final disposal of MSW are regulated through a number of general policy principles and international directives. It is imperative therefore to create awareness among local authorities, manufacturers, companies and generally society of the available varied technological solutions.

Integrated waste management solutions using the concept of industrial symbiosis (IS) have been developed and evaluated taking into account the European and national waste management legislation. IS, as part of the emerging field of industrial ecology focuses on the flow of materials and energy through local and regional economies. IS engages traditionally separate industries in a collective approach to drawing competitive advantage involving physical exchange of materials, energy, water, and/or by-products. The keys to IS are collaboration and potential synergies offered by geographical proximity and industrial function. Life Cycle Assessment (LCA) provides the methodological framework. LCA is conducted according to ISO 14040 Moreover, LCA used to describe the environmental impacts of products and processes while assessing the material and energy flows throughout their lifetime.

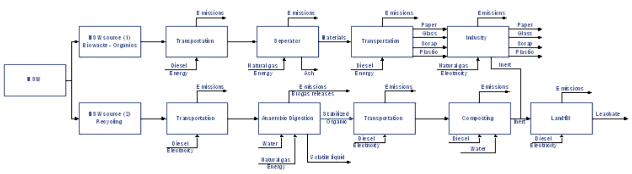

Figure 13. Waste management scenario: Waste is pre-treated and pre-sorted into biodegradable and non-biodegradable material for further anaerobic digestion and composting. Residues end in landfill. Plastic, paper and ferrous material are recycled.

Indicators of efficiency, effectiveness, and environmental and public health impacts are used to facilitate the comparative evaluation of the different MSW management scenario. Hence, material flow accounting, gross energy requirement, exergy and emergy intensity, local, regional and global emission and release intensity and morbidity or mortality indicators are used to support the comparative assessment.

This integrated framework was applied in the case of MSW management in the two larger cities in Greece, Athens and Thessaloniki, with a special focus on energy and material balance, including potential global and local scale airborne emissions as well as groundwater and soil releases. Public health impacts were assessed based on adverse effects on respiratory health, congenital malformations, low birth weight and cancer incidence.

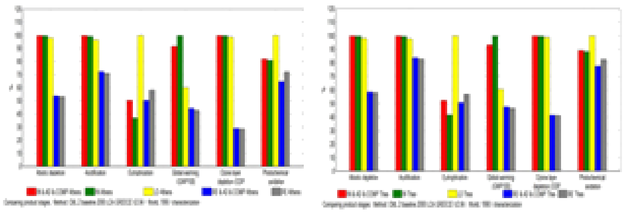

Figure 14. Impact categories of life cycle assessment for Athens and for Thessaloniki

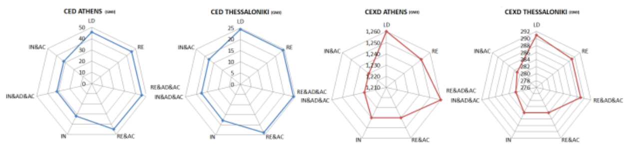

Figure 15. Cumulative Energy and Exergy Demand for Athens and for Thessaloniki

A significant and non-intuitive result is the fact that integrated framework analysis produces different conclusions than a simple environmental impact assessment based only on estimated or measured emissions. Taking into account the overall life cycle of both the waste streams and the technological systems and facilities envisaged under the plausible scenarios analyzed herein, modifies the relative attractiveness of the solutions considered. The results of the assessment based on selected impact indicators lead to the following conclusions: biological methods have the smallest abiotic matter, acidification potential, greenhouse gas effect, ozone depletion and photochemical oxidation among the waste management systems considered.

However, not all options are benign on the local environment and on the local population health, since both can be influenced by non-negligible local emissions.

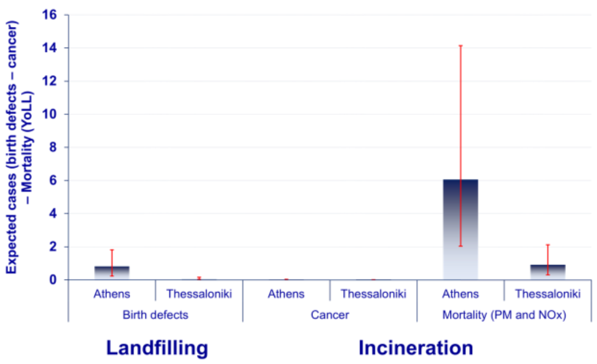

Figure 16. Health impact assessment among the various waste management options

As far as public health is concerned, adverse effects on respiratory health, congenital malformations, low birth weight and cancer incidences are still observed especially from incineration and landfilling.

Innovative waste management and energy recovery systems

Anaerobic digestion

Anaerobic digestion (AD) of organic material occurs in the absence of oxygen and the presence of anaerobic microorganisms. It occurs in three stages, Hydrolysis/ Liquefaction, Acidogenesis and Methanogenesis.

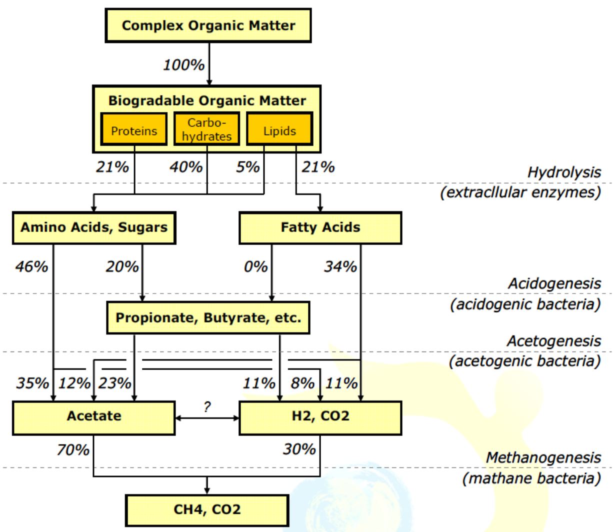

Figure 17. Anaerobic digestion process

The EnvE Lab apparatus contains a system of coupled four anaerobic bioreactors, of 6.5 l in volume each, equipped with stirrers for waste agitation. The digesters are single- stage units, which can operate both as CSTR and batch reactors.

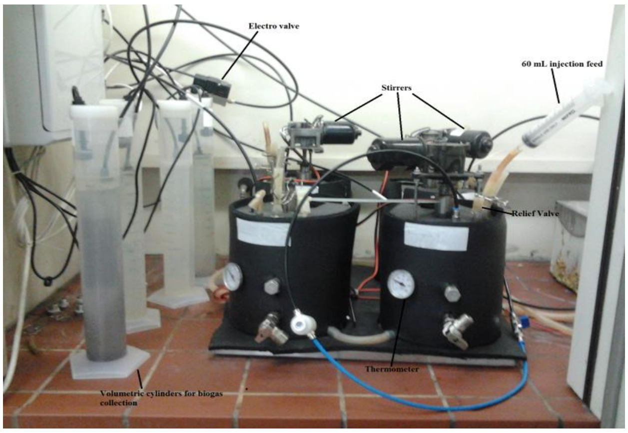

Figure 18. Anaerobic bioreactors

EnvE Lab research deals with anaerobic digestion from biodegradable matter in order to produce biogas (waste to energy). In particular, the organic fraction of Municipal Solid Waste (OfMSW) was used as feedstock trying to optimize the reactor operation considering the percentage of wastes and inoculums.

The four anaerobic digesters give to EnvE Lab the independence to compare different feedstock and conditions at the same time aiming at optimizing the design of integrated AD systems for different operational conditions, feedstock composition and treatment goals.

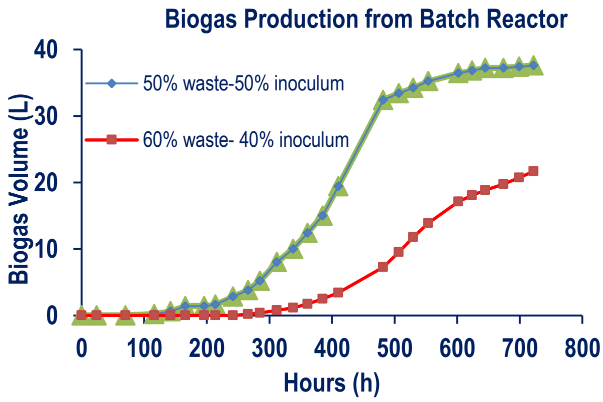

Figure 19. Biogas production from a batch work bioreactor using as feedstock the OfMSW 50% and inoculums 50%

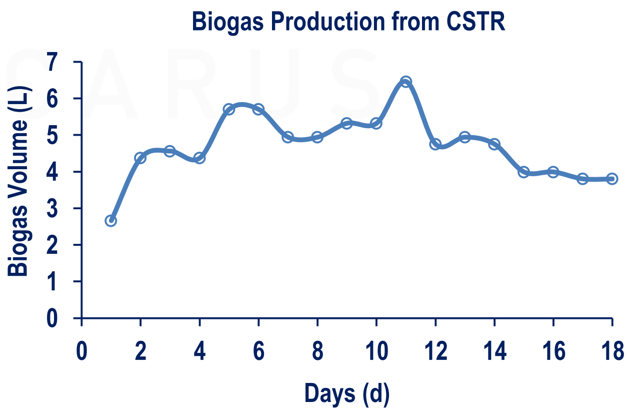

Figure 20. Biogas production from a CSTR bioreactor using as feedstock 0.2L/d of optimal waste

Waste-to-energy systems and algae photo-bioreactors

Valorization of zero or negative value raw materials has become the hot spot of the 21st century with the biological methods leading the way. From composting to the fourth generation bio-refinery, microorganisms are utilized thanks to their abilities to bio-convert different organic macromolecules into valuable materials and renewable energy resources. Throughout this quest for identification of renewable resources, great attention has been paid into the evolution of the anaerobic digestion into a robust process able to treat a plethora of mixed substrates. While microorganisms are able to valorize different waste streams, they have a number of inherent limitations which through appropriate management can be bypassed or ever used in advantage of another biological process in a win-win process scheme. One of these limitations is the inefficiency of anaerobic microorganisms to convert a number of natural macromolecules into biogas mainly due to slow hydrolysis.

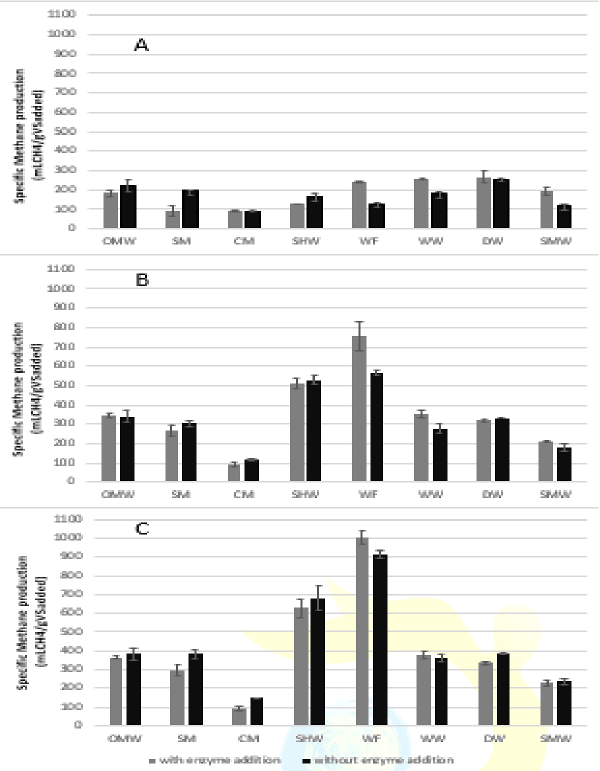

Figure 21. Specific methane production (mL/gVS_{added}) on days 5, 12 and 30 for the enzymatically pretreated and not pretreated substrates (Olive Mill Waste, Sterilized Mass, Cattle Manure, Slaughterhouse Wastes, White Fat, Winery Wastes, Distillery Wastes, Slaughterhouse, Solid Mill Wastes)

In order to improve the efficiency of the process toward these macromolecules, in the last couple of years a number of small scale digestion experiments took place in our laboratory where we assessed the effectiveness of initial enzymatic pretreatment enhanced by the addition of commercially available enzymes. Based on the generated data, the effect that the examined enzymes have on the anaerobic digestion of the mixed substrates can be divided into three categories:

A) No or negligible effect, as is the case of olive mill and distillery waste.

B) Positive effect on the process with the methane production taking place faster and the organic matter exhausts more rapidly. This category includes white fat and olive mill solid waste.

C) Negative effect with the methane production taking place slower and the cumulative methane production being lower when compared to the methane generated by the batches that no external enzymes added. This category includes cattle manure and sterilized mass.

Photo bioreactors

Another inherent limitation of anaerobic digestion is the generation of carbon dioxide during anaerobic respiration. This in some cases can be volumetrically equal to the generated methane. The presence of carbon dioxide in the biogas is undesirable as it is reducing the heating value of the gas while increasing storage and management costs. In order to reduce the concentrations of carbon dioxide from the biogas, we designed and constructed a bench-scale anaerobic digestion system coupled to photo-bioreactors where algae are employed for the valorization of the carbon dioxide, hydrogen sulfide and ammonia available in the biogas.

Figure 22. The photo-bioreactors within the temperature controlled cabinet

After harvesting algal biomass will be used for the recovery of high value added products, raw material for fuel manufacturing and industrial product development. Algae are a group of photosynthetic microorganisms that can fix carbon dioxide from different sources into biomass. During the last years this ability of algae has been explored in order to identify pathways through which the application of these species can reduce the environmental burden of human activities. Algae are an important carbon sink and their cells can contain more than 50% of fats and oils, sometimes rich in ω-3, from where pharmaceuticals or raw material for biodiesel production can be extracted. It noteworthy that for every kg of algal biomass, 1.65-1.83 kg of CO_2 must be consumed. The spent algae cells can be further valorised as activated carbon building blocks or substrate to anaerobic digesters.

The applicability of farm scale biomethanation plants for the valorization of the municipal organic wastes

Redirection of organic municipal waste away from landfills is one of the challenges that waste managers face every year. Only in Greece more than 2.7 million tons of municipal organic waste are generated annually. Currently most of these are landfilled, resulting in wastage of a resourceful substrate, over exploitation and pollution of surface and ground waters, as well as in releases of greenhouse gases into the environment.

Anaerobic digestion provides a waste management option for OFMSW, while offering the opportunity to recover marketable products both in the forms of biogas and slow release bio-fertilizers. As a result, less waste is dumped into landfills, while at the same time the process can be used by local authorities to meet the waste redirection targets set by the European Community Landfill Directive (1999/31/EC). As a way to improve the bio-methane production of AD systems, different types of waste-wastewater can be mixed and treated together in co-digestion schemes. Mixing of different substrates is not only desirable for improving methane recovery rates and reducing life cycle costs; it also provides better organic load removal efficiencies as an effect of C/N ratio correction, pH balancing and improvement on the buffering capacity of the treatment systems.

The experiments were performed under thermophilic conditions in batch and large volume laboratory digesters, with the feed rate of food waste to manure reaching levels as high as 70% based on VS loading, the total solids levels at 15.7% and the OLR at 6.85kgVS/m^3/d. At the higher feed rate the digestion process was slightly inhibited, probably due to sugar accumulation. In contrast waste mixtures containing up to 65.3% food waste with the OLRs as high as 6.2 kgVS/m^3/d with the influent TS levels up to 14.3% can be accepted by CSTR systems with no signs of inhibition.

Our results show that the addition of food waste to anaerobic digesters operating under manure monodigestion conditions can improve specific methane production by 86% and the volatile solids reduction by 19%. In a farm scale digester (3000m^3, HRT 21-d) the addition of food waste can result in a fourfold increase of cash flow by only slightly increasing operational costs due to pasteurisation requirements. Additionally, gate fees and carbon credits can further improve the financial performance of treatment facilities.

Valorization of semi solid pickling wastes, through bio-methanation pathways

Vegetable and fruit pickling and the subsequent canning is a multibillion Euros industry presenting great export potential with the gross European pickle production reaching the 1.6 million tons per annum. Pickling is a traditional method of preservation employed for the long term storage of vegetables and fruits under either an acidic brine solution or an acidic oily solution.

The waste assessed in the present work were:

a) pickled green peppers in brine,

b) pickled red peppers marinated with olive oil and

c) mixed green olives stuffed with red pepper and cheese based cream in brine.

These substrates have high total solids, significant fat and NaCl concentrations and acidic pH as an effect of the addition of acetic acid during pickling. The theoretical specific production of the substrates fluctuates between 435 and 561 $mlCH_4/gVS_{added}$. The experiments performed in batches and under thermophilic conditions with a retention time of 30 days.

The highest specific production offered by the green stuffed olives with 519 $mlCH_4/gVS_{added}$, followed closely by red peppers in oil with a yield of 488 $mlCH_4/gVS_{added}$. These values correspond to 92.4 and 99% of the theoretical production for these substrates. In contrast to the high yields exhibited by red peppers and stuffed olives, the bio-methane yield offered by the green pepper in brine was only 149 $mlCH_4$/gVSadded, i.e. the 34% of the theoretical production for this substrate. In order to overcome the inhibition of the monodigestion of the green peppers, these were assessed under co-digestion conditions together with cattle manure. Under these conditions the efficiency of the process improved by 32% with the yield reaching the 270$mlCH_4/gVS_{added}$.

Anaerobic digestion and co-digestion of pickling solid waste and cattle manure was performed successfully with significant volumes of biogas recovered. The red peppers and the stuffed olives, thanks to their high content in fats and organic acids, offer very high specific and volumetric methane productions. Unfortunately, green peppers assessed contain significant concentrations of NaCl that is a known inhibitor of methanogenesis. The successful application of co-digestion reveals the merits of the combined treatment of substrates for minimizing inhibitor stress and improving the chances of success.

Air pollution related topics

PM emissions from different vehicle types and implications to human exposure

A study was carried out so as to investigate the effect of vehicle mileage, age and the respective emissions class on "real life" emitted PM size distribution and actual human respiratory tract deposition. From the study it was found that both mileage, age and emission class have almost no effect on the size distribution of the exhaust gas particulate released into the environment; about half of the examined vehicles with low mileage (Figure 24) were found to release particles of aerodynamic diameter above 10μm. Newer vehicles with low mileage are substantial sources of soot and metal particles with median diameter of 200 nm with a higher surface area (Figure 26), up to 89,871.16 cm^2/cm^3. These particles tend to deposit in the lower part of the human respiratory tract (Figure 27), as well as to adsorb a higher amount of toxic components (heavy metals, PAHs) compared to particles with smaller active surface. A key finding of the study is that special attention has to be paid to the lower aerodynamic diameter related to newer diesel vehicles, their higher specific surface and how this is translated into actual increased human exposure and, consequently, health risk.

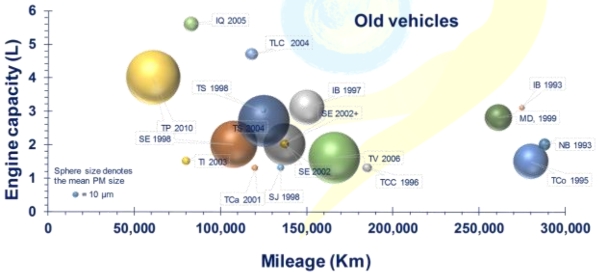

Figure 23. The mean diameter (denoted by the sphere size) of the exhaust gas particulates in the cars with mileage

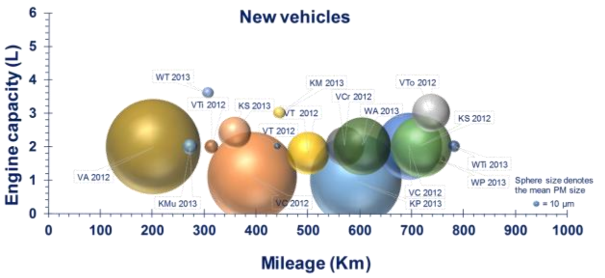

Figure 24. The mean diameter of the exhaust gas particulates in the cars without mileage

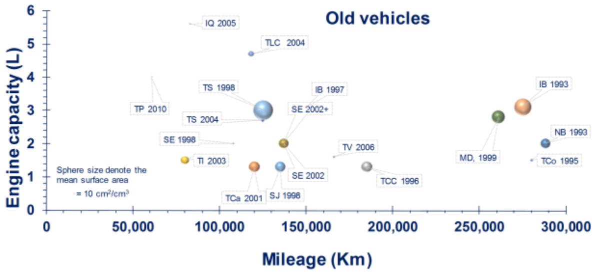

Figure 25. The specific surface area of the exhaust gas particulates in the cars with high mileage

Figure 26. The specific surface area of the exhaust gas particulates in the cars with low mileage

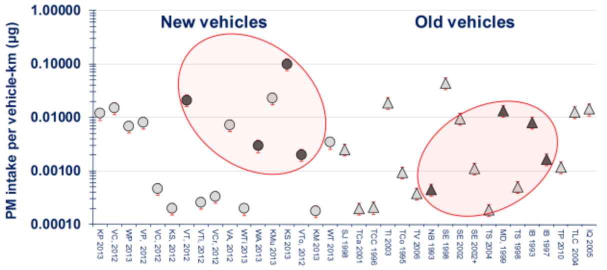

Figure 27. PM deposited across HRT per km traveled by the respective vehicles. Dark grey points indicate diesel vehicles, light grey points indicate gasoline vehicles

Assessment of PAHs exposure and genotoxic effects

Genotoxic effects of inhaled particulate matter (PM) are mainly attributed to absorbed polycyclic aromatic hydrocarbons (PAHs). Human respiratory tract (HRT) deposition of a specific particle depends on its aerodynamic diameter. Thus, xenobiotics contained in finer particles can easily be transferred in human body via systemic circulation. Benzo[a]pyrene (B[a]P) is the only PAH classified as known carcinogen to humans by IARC.

An extensive campaign was carried out from January to April 2013 at two locations in the urban area of Thessaloniki to determine the chemical composition of urban aerosols and to correlate their toxicity with biomass combustion as a way of residential heating. PM1, PM2.5 and PM10 particles were collected in Teflon filters using low flow air samplers in two air pollution monitoring stations, representative of urban/residential and traffic influenced pollution respectively.

Nineteen individual PAHs were analyzed by GC/MS and concentrations in air were calculated for both monitoring stations. Potential cancer risk due to exposure to the mixture of urban ambient air PAHs was calculated using the toxicity equivalent factor (TEF) approach based on Benzo(a)pyrene (B[a]P) (Figure 28).

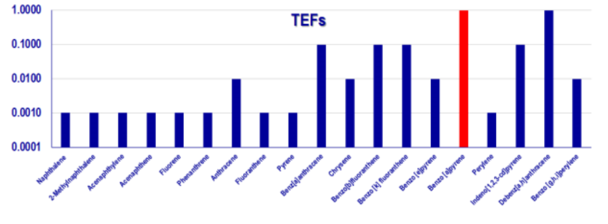

Figure 28. Toxic Equivalent Factors (TEFs) for the different PAHs, on the assumption that the TEF for B[a]P is equal to 1

The TEQ (Toxicity Equivalent Quotient) (carcinogenicity equivalent, in ng/m^3) was calculated by multiplying the concentrations of each compound in the PAH mix with the respective TEF for cancer potency relative to BaP. Daily inhalation rate (*IR*) and deposition fractions of particulate matter to the main regions of the respiratory system were calculated for eight age groups of human population. The ultimate cancer risk was estimated for each age group using the CEPA Inhalation Unit Risk (*IUR*) for B[a]P.

The results showed that PM (PM1, PM2.5, PM10) and PAHs concentrations, during the cold period, were higher in the urban background monitoring station than in the traffic station. This pattern was attributed to biomass combustion, which can be considered as the primary source of PAHs in the populated areas of Thessaloniki during the last two years winters. PAH and levoglucosan levels were highly correlated, indicating that particles emitted from biomass combustion are more toxic than PM emitted from other sources. The median ΣPAHs levels at the urban background site are 8.31, 9.82 and 9.91 ng/m^3 for the PM1.0, PM2.5 and PM10 fraction respectively. At the traffic station, the corresponding levels are 2.82, 3.52 and 3.92 ng/m^3 (Figure 29). Therefore, practically, most of the PAHs are adsorbed in fine particles (PM2.5 and finer).

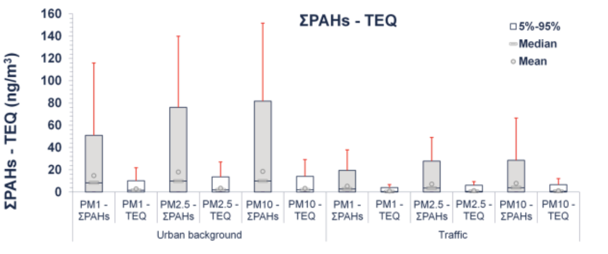

Figure 29. Total PAHs concentrations for the two monitoring stations

At the urban background site median TEQs are 1.61, 1.93 and 1.96 ng/m^3 for PM1.0, PM2.5 and PM10; the corresponding values at the traffic site are 0.43, 0.63 and 0.69 respectively (Figure 29). The TEQ at the urban background monitoring station is 3 times greater than the equivalent value found at the traffic station. TEQ/PM ratios at the urban background site are 0.091, 0.083 and 0.066 ng/μg PM for PM1, PM2.5 and PM10 respectively. At the traffic site, the respective ratios are 0.045, 0.44 and 0.032 ng/μg PM.

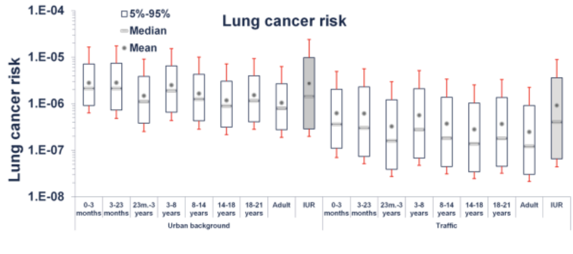

Figure 30. ICR calculated for each age group

The estimated lung cancer risk was non-negligible for residents close to the urban background monitoring site. Higher risk was estimated for infants and children, due to the higher bodyweight normalized dose and the human respiratory tract (HRT) physiology. HRT structure and physiology in youngsters favor deposition of particles that are smaller and more toxic per unit mass. In all cases, the estimated risk (5.7E-07 and 1.4E-06 for the urban background site and 1.4E-07 to 5.0E-07 for the traffic site) was lower to the one estimated by the conventional methodology (2.8E-06 and 9.7E-07 for the urban background and the traffic site respectively) that is based on Inhalation Unit Risk; the latter assumes that all PAHs adsorbed on particles are taken up by humans. With the methodology proposed herein, the estimated risk presents a 5 to 7 times difference between the two sampling sites (depending on the age group). These differences could not have been identified had we relied only on conventional risk assessment method. Consequently, the actual cancer risk attributable to PAHs on PM emitted from biomass burning would have been significantly underestimated.

External and internal exposure assessment to PAHs from multiple sources

Exposure to PAHs has became of particular scientific and regulatory interest the last year, especially in view of the potential for petroleum substances to be included in the different REACH processes (notably Evaluation and Authorisation). In order to meet the requirements of REACH, it is of particular importance the capability of models to predict direct (arising from the use of substances) and indirect (e.g. fuel combustion) PAH exposures. The capabilities of the developed computational platform for addressing integrated multi-source, multi-route (MSMR) exposure to PAHs was demonstrated in a workshop organized by CONCAWE. A typical scenario that was demonstrated, dealt with the prediction of the environmental fate and exposure of annual emissions of 400 tones B[a]P in air within EU, and for regional emissions of 15 tons. Distribution across different environmental media and the contribution of different pathways and routes to the overall exposure were estimated (Figure 31) both for adults and children.

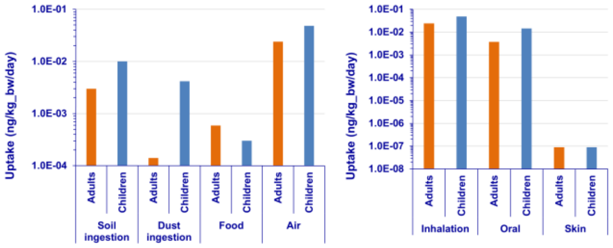

Figure 31. Contribution of pathways and routes in aggregate PAHs exposure

Moreover, internal exposure to B[a]P and urinary concentration of 3-OH-B[a]P (the most specific B[a]P metabolite) was also estimated.

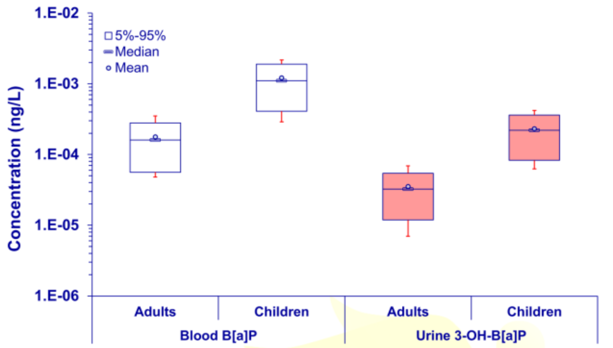

Figure 32. Internal exposure and urinary concentrations of major B[a]P metabolite

The time-dynamic nature of the computational platform, allows also to capture environmental, exposure and internal dose dynamics in high temporal resolution, quantifying the effect of real-life different exposure conditions (such as driving, eating smoked fish or operating an open fireplace) in actual uptake, internal dose and expected biomarker urinary levels (Figure 33).

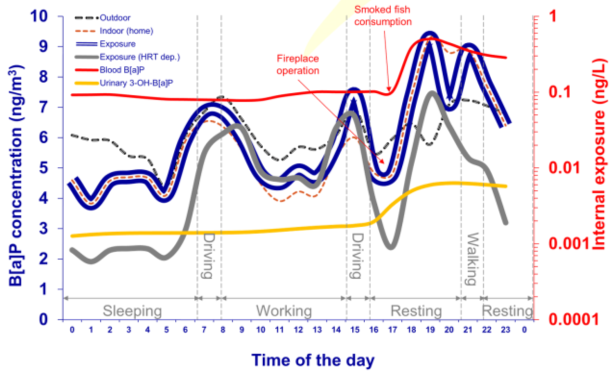

Figure 33. Diurnal variability of environmental, exposure and internal dose dynamics

Combined or multiple exposure to health stressors in indoor built environments

There is a lot of evidence and studies on non-occupational indoor risks. Often, however, the focus is on health outcomes of exposure to single stressors and multiple risks are often related to confounding in epidemiological studies. As a consequence, these studies, do not necessarily provide a good overview of multiple exposure to these health stressors and their association to adverse health outcomes per se. In fact aside simple additivity of effects and some specific cases of exposure to at most two simultaneous stressors, which may enhance or counteract each other, the actual evidence on health effects of co-exposure to multiple stressors is limited.

Among the several health threats, exposure to multiple chemical agents still remains the silent threat: poor indoor environment quality (in terms of exposure to chemicals) is not always perceived by the occupants. As a result, occupants are continuously exposed to a cocktail of carcinogens (benzene, formaldehyde, PM-PAHs) and endocrine disruptors (phthalates, PCBs). The combined effects of these chemicals are still not sufficiently elucidated, since their physic-chemical and biochemical properties would favor multiple ways of interaction upon human uptake (Figure 34); there might be synergies in effect (e.g. PAHs and nitrosamines of ETS, both causing lung cancer), or they might inhibit each other's metabolism – this is the case for the almost ubiquitous indoors BTEX mixture. In any case, although further investigation on the mechanisms elucidating mixture toxicity is needed, no significant departure from additivity in the health effect assessment was observed for the concentrations encountered usually in non-occupational settings.

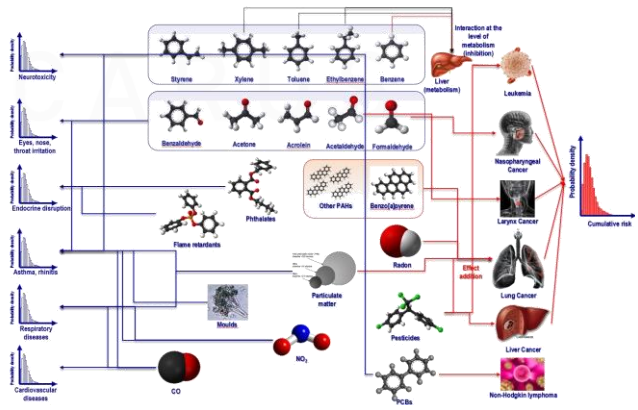

Figure 34. Multiple ways of interaction for chemicals

Combined exposure to chemical and biological agents in the indoor environment may result in increasing risk of adverse health effects. A case that stands out in this context, is the study of co-exposure to chemicals from carpeting and mould, which was conclusively shown to produce adverse health effects beyond additivity; indeed the observational data hint to synergistic mechanisms coming into play or to enhanced physiological susceptibility of adults to biological agents when co-exposed to phthalates and other organic chemicals emitted from building materials and consumer goods frequently used in residential settings indoors.

Experience from previous projects

Urban Reduction of GHG Emissions in China and Europe (URGENCHE)

URGENCHE was a project aiming to develop and apply a methodological framework for the assessment of the overall risks and benefits of alternative greenhouse gas (GHG) emission reduction policies for health and well-being in China and Europe.

Under the perspective of urban transportation, the co-benefits to urban air quality, noise and public health were investigated from the introduction of greenhouse gas (GHG) emission reduction policies to the city of Thessaloniki and the Great Thessaloniki Area (GTA). The traffic related policies implemented, included the introduction of underground rail in the city centre and changes in vehicle composition, i.e. allowing a larger share for the diesel engine passenger cars, the hybrids and the electric cars.

Air and noise pollution were assessed for a baseline scenario in year 2010 and two future scenarios in year 2020, a business-as-usual (BAU) and a GHG emission reduction scenario (CO2 scenario). This assessment was carried under an integrated methodological framework, composed of a series of interconnected models and repeated for the years 2010 and 2020. The models used, included the (a) SIBYL, to project vehicle stock numbers; the (b) VISUM, to simulate traffic flow as a result of changes in travel demand; the (c) COPERT IV, to compute the pollutant emission (PM10, PM2.5, NO_2, NO_X, O_3, CO and benzene) per vehicle engine and type; the (d) OSPM to compute pollutant concentrations in traffic corridors; the (e) CALPUFF, to compute pollutant concentrations on motorways and urban/peri-urban roads; and the (f) NMRB-2008, noise model to evaluate traffic noise generation and its propagation from traffic corridors and motorways under the ISO 9613-1 and the 9613-2 constraints.

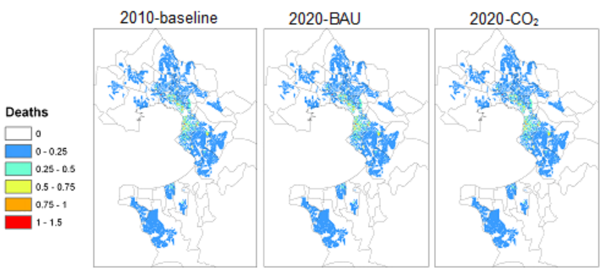

Figure 35. Spatial distribution of annual number of deaths attributed to PM_{10} in 2010, 2020-BAU and 2020-CO_2

Exposure to air population was assessed via the inhalation pathway and its health impact was estimated by concentration response functions on high resolution population data (per building block, differentiated by age and gender). The health end points computed include annual mortality attributable to PM10 and NO_2 exposure and the leukemia lifetime expected cases due to benzene exposure, which were aggregated at the municipality level (Figure 35).

Noise was computed from the shortest distance of Source (e.g. motorway) to the Receptor (e.g. building block of a particular height) and its exposure was weighted by the population and differentiated between each municipality in the Thessaloniki Area. The health end points computed include, sleep disturbance, sleep annoyance due to road transport and myocardial infractions.

The impact of the Greenhouse Gas (GHG) emission reduction scenarios to health was identified to be significant. Simulations show that traffic flow will decrease by 33% on roads in direct proximity to the metro line (e.g. Monastiriou, Egnatia, Nea Egnatia, Delfwn), by 44% on roads within the historic center and by 22% in all adjacent roads to the historic centre. These reductions in flow were further amplified by changes in the traffic mode, where diesel, hybrids and electric cars will constitute 22%, 7.7% and 2% respectively, to the total vehicle fleet.

It was estimated that for the municipality of Thessaloniki, the expected decrease (%) in the annual number of deaths for the GHG scenario were 8% and 11% attributed to the PM10 and NO_2 respectively and 27% to the leukemia lifetime expected cases due to Benzene. In comparison, for the municipality of Panorama, the expected % decrease in the annual number of deaths for the GHG scenario are 1% and 23% from PM10 and NO_2 respectively and 33% to the leukemia lifetime expected cases due to benzene (Figure 36).

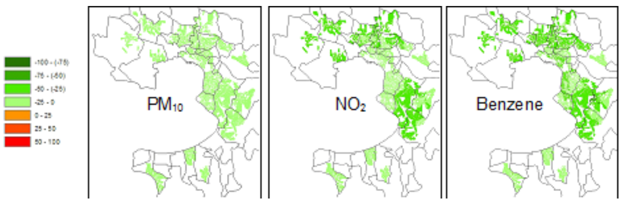

Figure 36. Decrease (%) in the annual number of deaths for the GHG scenario

Similarly the highest reductions in sleep annoyance due to road transport noise and the myocardial infractions were identified in the municipality of Thessaloniki, where the aforementioned policies have the highest impact.

Monitoring air quality in Charilaos Trikoupis bridge

The Charilaos Trikoupis bridge, known as bridge of Rio-Antirrio (Figure 37), is one of the world's longest cable-stayed bridge of multiple openings in the world, with a total length of 2,252 meters. It connects Western Greece with the rest of the country.

Figure 37. Charilaos Trikoupis bridge

Six monitoring campaigns were realized in the course of the last three years. The exact periods of the two annual campaigns were selected taking into account the high traffic seasons according to a careful examination of the bridge traffic patterns. In each of the campaigns $PM_{2.5}$, PM_{10} and TSP were sampled every 24 hours near the edges of the bridge located in the urban areas of Rio and Antirrio respectively, using low (for PM2.5 and PM10) and high (for TSP) volume automatic sequential samplers. Dynamic measurements of CO, NO_x, SO_2, $PM_{2.5}$ and PM_{10} were also performed continuously during the 10-day periods. TSP were collected on quartz filters (203 mm × 254 mm) in order to determine lead (Pb). Lead concentrations were measured using an inductively coupled plasma mass spectrometer (ICP-MS). Moreover, meteorological data (wind speed and direction, temperature, cloud cover and humidity) were recorded. The pollution data were analyzed statistically and the quality of the air was characterized according to the US Environmental Protection Agency indicators and the European Common Air Quality Index framework.

The results indicated that air pollution levels are in generally below the regulatory thresholds. Across the three summer sampling sessions (N = 10 days) the average PM_{10} daily concentrations at the Rio site were 19.7 μg/m^3, 20.1 μg/m^3, 19.2 μg/m^3 only slightly higher than that at the Antirrio site that were 17 μg/m^3, 17.5 μg/m^3 and 12.6 μg/m^3 (for the 1st, 3rd, 4th periods respectively). The $PM_{2.5}$ were 8.7 μg/m^3, 10.61 μg/m^3, 8.9 μg/m^3 at Rio site while at Antrirrio were 7.8 μg/m^3, 9.22 μg/m^3, 7 μg/m^3 (for the 1st, 3rd, 4th periods respectively). Moreover, the traffic emissions from the bridge are not the main source of air pollution in the area. During the winter period of sampling (2nd) $PM_{2.5}$ and PM_{10} levels were below 25 and 50 μg/m^3 on both sides of the bridge almost every day. These limits were exceeded only one day (5/12/2013) on the side of Antirrio (26.4 and 52.2 μg/m^3 for $PM_{2.5}$ and PM_{10} respectively). However, during the winter period, $PM_{2.5}$ and PM_{10} levels are higher due to the use of light oil and biomass burning for space heating. Pb levels were very low; the average daily value recorded (2.6 ng/m^3) is two orders of magnitude lower than the regulatory limit of 0.5 mg/m^3. Hourly average concentrations of CO, SO_2, NO and NO_2 for the both sides were below the regulatory thresholds. Overall the contribution of the Charilaos Trikoupis bridge to the surrounding air pollution levels is very low. This is the result of the relatively low daily volume of vehicles (~10000 vehicles per day), the respective traffic fleet composition (~80% of the traffic fleet are passenger vehicles) and the speed limit (80 km/h) which does not favor traffic emissions. In addition, the strong and frequent winds further contribute to the rapid dispersion of the emitted pollutants. The air pollution data was also characterized according to the United State (US) Environmental Protection Agency (EPA) indicators and the Common Air Quality Index framework.

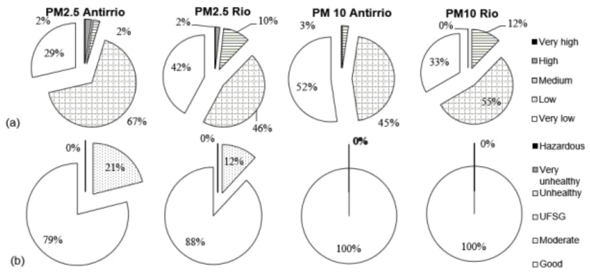

Figure 38. (a) European Common Air Quality Index framework, (b) US Environmental Protection Agency indicators

The US EPA AQI was calculated for NO_2, PM2.5 and PM10 and the results showed that the main driver of associated health risks in Rio-Antirio Bridge was PM2.5 at both locations. Figure 38 illustrates that during the 4 periods of measurements the daily air pollution was characterized as "moderate" with 21% and 12% for the Rio and Antirrio, respectively. But it has to be noted that the 87% of these measurements was observed the winter period. Simultaneously, CQAI showed that in Rio and Antirrio PM2.5 was also again the dominant pollutant. It was highlighted that the 2% of the measurement was at level of the high pollution and this percentage was observed during the winter. The highest concern is that ambient air PM levels in the urban environment are greatly affected by seasonal effects of emissions patterns and deposition processes occurring in the different regions of the human respiratory tract, which are related to the physiology/morphology of the respiratory system and the PM size distribution. Despite the lower level of traffic during the winter period, higher levels of PM were observed then. That could be related to the relative increase in all-size fraction of PM emissions in Greece, especially during the cold months of the year due to biomass combustion for space heating. Yet, the results of the AQI calculations indicate that care has to be taken to cater to the needs of susceptible individuals. US EPA remarks that "moderate" level of pollution can be alarming for a very small number of people.

Application of the ICARUS methodology in Greece - the misuse of biomass

Health impact and monetary cost of exposure to particulate matter emitted from biomass burning in Thessaloniki

A major issue related to the extensive use of biomass as a space heating means during wintertime in Greece is the high levels of particulate matter. The study deals with the assessment of health impact and the respective economic cost attributed to particulate matter (PM) emitted into the atmosphere from biomass burning for space heating, focusing on the differences between the warm and cold season in 2011-2012 and 2012-2013 in Thessaloniki (Greece). Health impact was assessed based on estimated exposure levels and the use of established WHO concentration-response functions (CRFs) for all-cause mortality, infant mortality, new chronic bronchitis cases, respiratory and cardiac hospital admissions. Monetary cost was based on the valuation of the willingness-to-pay/accept (WTP/WTA), to avoid or compensate for the loss of welfare associated with illness.

The results of the 2012-2013 measurements were compared to the ones made in 2011-2012 to understand better the effect that different policy measures regulating the market price of heating fuel in tandem with the incumbent economic crisis in Greece and other countries in the European South may have on non-occupational exposure of the urban population to particulate matter and the associated health and monetary impact. Own-price elasticity of light heating oil was taken as el_{oil} = -0.39. A field survey encompassing ca. 300 households across the greater area of Thessaloniki implemented using the on-line SurveyMonkey tool provided consumer behavior information that was used to generate the cross-fuel elasticity table below.

The scenarios are based on reasonable assumptions and existing trends related to the energy market; however the interplay of multiple factors such as financial pressures or incentives might result in unexpected figures (as occurred with the increased biomass use), favoring one technological solution for space heating over another. Through analysis of specific scenarios we highlighted the attributable differences in public health burden, should specific space heating practices be adopted.

Table 1. Cross-price elasticities of alternative space heating energy carriers

	Light heating oil	*Natural gas*	*Biomass*	*Electricity*
Light heating oil	----	n/a	-0.97	-0.24
Natural gas	n/a	----	n/a	n/a
Biomass	-1.03	n/a	----	0.25
Electricity	-4.1	n/a	3.98	----

n/a: sufficient data non available to support the estimation of elasticity

The different policy scenarios examined, resulted in lower average urban background concentrations (Table 2).

Table 2. Fuel/technology use distribution and corresponding urban background concentrations

	Oil	**Natural gas**	**Biomass burning**	**Electricity**	**PM2.5 (μg/m³)**
2011-2012	44.0%	40.0%	5.6%	10.4%	**41.2**
2012-2013	22.3%	40.0%	26.7%	15.7%	**62.6**
Scenario 1	38.5%	41.5%	10.0%	10.0%	**36.3**
Scenario 2	43.5%	41.5%	5.0%	10.0%	**28.4**
Scenario 3	23.5%	62.5%	4.0%	10.0%	**26.5**
Scenario 4	20.0%	70.0%	0.0%	10.0%	**20.0**

Results showed that long term mortality during the 2012-2013 winter increased by 200 excess deaths in a city of almost 900,000 inhabitants or 3540 years of life lost, corresponding to an economic cost of almost 200-250m€. New chronic bronchitis cases dominate morbidity estimates (490 additional new cases corresponding to a monetary cost of 30m€.

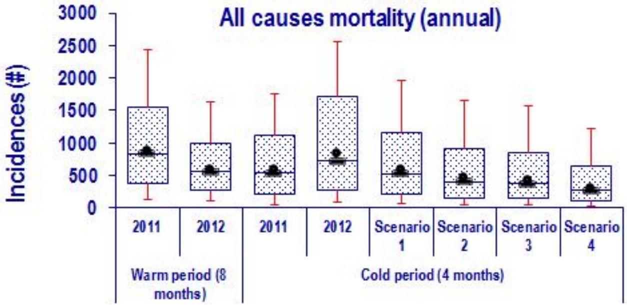

Figure 39. Estimated annual mortality due to PM exposure under current situation and "what if" scenarios

Estimated health and monetary impacts are more severe during the cold season, despite its smaller duration (4 months).

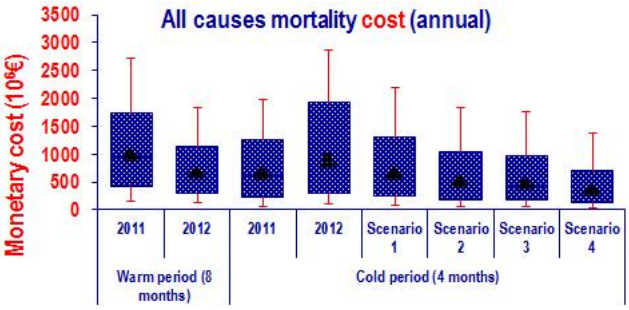

Figure 40. Estimated socioeconomic cost of PM attributed mortality based on total welfare change

Policy scenario analysis revealed that significant public health and monetary benefits (up to 2b€ in avoided mortality and 130m€ in avoided illness) might be obtained by limiting the biomass share in the domestic heat energy mix. Fiscal policy affecting fuels/technologies used for domestic heating needs to be reconsidered urgently, since the net tax loss from avoided oil taxation due to reduced consumption was further compounded by the public health cost of increased mid-term morbidity and mortality.

Recommendations on the technologies of pellet boilers

EnvE Lab expert opinion was requested by the General Secretarial of Industry for providing recommendations on the PM emission specifications of pellet and wood combustion boilers available in the Greek market. This reflected the concerns about the current emission levels of biomass combustion of modern devices present in the Greek market; the question posed was whether an intermediate level of emissions limit should be implemented before the Eco-Design directive becomes effective in 2018. In order to address this question, a thorough review related to technological aspects of boilers technology as well as a survey of the current situation in the Greek market were carried out.

From the review, it was found that the mass of particulate emissions is 180 times higher for old construction boilers compared to boilers based on newer specifications. Moreover, the number of particles emitted increases with an increase in emissions of non-oxidised gaseous components. Since the distributions of the number and mass depends on the particle size, it is concluded that the emission of particles, in particular ultrafine (size <100 microns) is amplified by non-ideal combustion conditions. Pellet burning results in coarser particle emissions compared to liquid fuels. The size distribution of aerosols is influenced by many factors such as the humidity of the fuel, the content of ash and the combustion process.

The European Committee for Standardization (CEN) has adopted standard EN 303-5 on 10-05-2012. This standard classifies the boilers into 3 categories, setting thresholds for their performance and emission limits for boilers that burn solid fuel. The boilers using as fuel solid biomass for non-industrial use in the Greek market intended for use in heating installations must comply the minimum performance and quality limits of exhaust gas set by the standard ELOT EN 303-5 according to Class 3. For this reason, the EN 303-5 is often used by local authorities as part of their regulations, to promote the purchase of high efficiency boilers and to create incentives for the use of efficient boilers with low emissions. This is the only European standard for boilers. Besides this standard apply another 4 standards for small residential applications of biomass:

- *EN 13240: For heaters - Solid Fuel*
- *EN13229 and EN 12815: For cooking Solid-Fuel fireplaces*

According to research conducted in Greece there are about 18 companies which manufacture pellet boilers and solid fuel some of which manufacture and fireplaces and stoves. It is important to stress that many of these companies have EN 303-5 with solid fuel boilers to category 3 but some of them have even certification of class 4-5, while the pellet boilers usually belong in category 4-5. Given the implementation of Directive 2009/125 / EC on Eco-Design requirements for (a) boilers and (b) local space heaters fired by solid fuels in 2018, the projected emission values Class 5 (40 mg/m^3) will be significantly reduced compared to the class 3 emission levels (150 mg/m^3). The technology and emissions of class 3 devices are closer to those of classes 1 (200 mg/m^3) and 2 (180 mg/m^3). Therefore, the reduction of emissions from existing boilers must be combined with changes in the technology, which will include the installation of electrostatic filters, the addition of secondary combustion, the increase of the gas paths inside the boiler and the construction of reverse steering technology boiler flame. Because the modification of existing boilers Class 3 are difficult to be transformed into class 4-5, a measure that would contribute significantly to reducing actual emissions is the use of better quality fuels.

The above analysis of available data shows that around 66% of Greeks biomass boiler manufacturers produce devices Class 4 and 5, i.e. with emissions below 100 mg/m^3. Emissions from the biomass boilers can be further reduced by using good quality biomass in accordance with the technical specifications of boilers. We may conclude that it is legitimate to establish an intermediate emission limit to 100 mg/m^3 for all Greek construction companies in order to push them towards more rapid harmonization with Community policy on eco-design (eco-design) by on the one hand and to protect public health from excessive aerosols emissions as occurred in the winter periods 2012-2013 and 2013-2014.

ICARUS ambition

Advances of the proposal beyond the state of the art

The most important advances of the proposal beyond the state of the art are

- Use of data and model fusion across the impact pathway chain of calculations to optimize use of fit-for purpose models and computational techniques based on artificial intelligence with a view to minimizing residual uncertainty in policy making for air quality improvement and climate change mitigation.
- Use of agent-based modelling (e.g. GAMA) informed from wearable technology sensors to capture individual spatio-temporal behaviours for modelling individual exposure taking into account societal dynamics factors modulating the overall results of policy actions.
- Mitigation of climate change and reduction of air pollution is addressed simultaneously in one environmental protection strategy instead of developing separate strategies for climate change mitigation and air pollution control or even separate strategies for different pollutants (e.g.PM10) and sectors (e.g. transport).
- Estimation of health impacts is based on the estimations of the uptake of pollutants instead of using the concentration in ambient air in the urban background as indicator.
- Both policies that initiate technical measures and non-technical measures are analysed.
- New approaches for enabling citizen participation in decision-making using open internet platforms.
- Participatory design methods for the development of data visualisations are used to enable a wide range of policy-makers and the public to understand the implications of the research and the related policy options.
- Development of policy options for mitigation and adaptation measures on city to European scales with recommendations for policy formulation and response.
- Ensure the outcomes of the project are translated to input useful to decision-makers, with a strong focus on stakeholder engagement in research delivery and design and organisation of dissemination activities.
- Citizen involvement in the project and evaluation of their capacity to drive the process and bring about the actual environmental impact.
- By the end of ICARUS, we will be able to make direct cross-sector policy-relevant recommendations on existing, retro-fit, or new technological and non-technological options can be better designed to improve air quality and reduce carbon footprint and promote health and prevent disease, especially in urban contexts and with cross border implications. This will ensure that the 'Health in all Approach Policies' Agenda also applies to the EU's urban environment. Through the use of scenario analysis, these ICARUS recommendations will be applicable not only to current circumstances, but also to futures where pressures on environment, due to climate and other environmental change, will increase. Our ultimate ambition is for the EU Member States and beyond to better design and implement appropriate abatement strategies to improve the air quality and reduce the carbon footprint in European cities for health and well-being promotion to address the public health challenges of the 21st Century, and to be prepared for future developments including climate change.

Innovation potential

25% of urban population lives in areas where the EU reference values for the protection of human health are regularly exceeded. Cities are uniquely vulnerable to the effects of climate change and air quality due to their dependence on complex and often ageing and fragile infrastructure, their proximity to sources of natural hazards such as rivers and coastlines, and their role as a focus of population movement. Managing these challenges requires significant innovations, such as:

• transforming urban mobility management systems,

• improving energy production and distribution systems,

• ensuring smart and cost-effective building technologies.

ICARUS will identify and propose effective technological and non-technological measures and policy actions to improve air quality and reduce the carbon footprint of European cities through an integrated approach. Science, technology and socio-economic aspects are dealt with jointly to maximize the uptake and impact of the proposed measures.

ICARUS will deliver an innovative framework for urban impact assessment in support of air quality and climate change governance in EU Member States. It will also produce and deploy web-based tools to estimate the carbon footprint and air pollution associated with both technical and non-technical mitigation measures and engaging web- and phone-based software for citizen awareness and motivation.

An important innovative contribution of the ICARUS project is that long-term policies will be established and justified together with city leadership, stakeholders, and the citizens being aware of the uncertainties, costs and benefits for their implementation. In this context a thorough evaluation of the implementation potential for the policies in each ICARUS city will be implemented.