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1 Executive Summary

This report gives an overview of the main salient recommendations of the ICARUS consortium to the key societal stakeholders linked to air quality and climate change in cities across Europe. This includes recommendations geared towards policy makers at different administrative levels (from supra-national, i.e. European institutions, to national, regional and local authorities responsible for environmental management and public health protection). In addition to policy makers as such, in the frame of the citizen science and citizen engagement concept of ICARUS specific recommendations are given to actors in specific activity sectors, from industry to civic society organisations, NGOs and lay persons.

Of particular importance are the recommendations distilled from the ICARUS team experience within and outside of the project boundaries on the link between environmental policies at the urban level and citizen's health. This series of statements covers sustainable mobility and active transport issues such as cycling, logistics optimization and freight management in cities, energy-relevant interventions such as widespread district heating. Key suggestions include operational and methodological advice on cost-benefit analysis of the different alternative policy options and the appropriate level of their implementation. Special attention is paid to the need to consider the co-benefits of climate change mitigation and air quality improvement measures on public health, taking in particular account of societal vulnerability and the effect of socio-economic status in health vulnerability of the population.

Policy efficiency is an important feature of all win-win solutions in EU cities, while measure integration across sectors and environmental objectives is a sine qua non for successful transition strategies aiming to deliver optimal solutions addressing societal concerns effectively and efficiently. Performance indicators are key drivers for the implementation of successful transition policies and measures. As such, population exposure and inhalation-bound intake of airborne pollutants is the indicator proposed by ICARUS as the right metric against which to measure success of air pollution and greenhouse gas emission abatement measures. On the technological front, ICARUS has demonstrated the attractiveness and rationale for the use of advanced sensor technology to improve the targeting of measures leading to reduction of hazardous emissions into the atmosphere. Finally, development of action on the city level through visioning processes that allow stakeholders to consider different potential futures and plan in different (co-creative) ways the urban environment has been shown to bear great potential for overcoming the current hurdles to urban transition toward smart, healthy and green cities in Europe.

Recommendations for reduction of air pollution from outdoor and indoor sources and for the assessment, monitoring and management of indoor air quality have been underlined in this report. Quality of indoor air is key to public health promotion in cities given the exorbitant amount of time we all spend (> 80%) indoors over the year. Coupled to reduction of airborne pollutants is the reduction of greenhouse gas emissions that goes hand-in-hand with air quality enhancement in the ICARUS perspective. Here again, a synthesis of salient recommendations is given in this report covering the sectors and activities that have the highest multiplier effect on improvement of the current state of affairs. The final part of the report is dedicated to information campaigns towards citizens to reduce their exposure to airborne pollutants – key recommendations are given in order to enhance the outreach of the project and realise its technical and transformational potential.

2 Recommendations to policy makers

2.1 Main recommendations linking environmental policies and health

Key messages emerging from the analysis of the policies/measures considered in the different ICARUS cities and shared with stakeholders include:

- Measures such as large scale/city-wide sustainable mobility interventions covering synergetic effects of public transport, walking, cycling focusing on all population groups combined with clean vehicles, and greater use of alternative fuels, have shown the greatest potential for significant reductions in pollutant emissions and consequently health effects. These measures showed in addition the higher potential to be easily scaled up to address the needs of a larger share of the urban population.

- Additional air pollution reduction advances could be reached through policy measures that encourage cycling, either by improving cycling infrastructure or increasing the availability of bike-sharing systems and especially through their further integration with public transport.

- Efficient logistics and freight distribution are policy measures that have shown significant environmental improvement potential – although their impact on air pollution is relatively small, they contribute to the quality of life and wellbeing in cities. In most cases, up-scaling might help to maximise their potential benefits

- In the energy sector, significant air pollution and health-related improvements are only evident from large-scale implementation attempts, such as the enhancement of district heating, which could be further increased by addressing the fuel technologies behind them.

- The results concerning the economic dimension are promising as the majority of the measures analyzed have shown a positive cost-benefit ratio. However, we need to underline the fact that economic impacts included in some of the measures have not considered for other measures, due to the lack of reliable data. Thus, further work in this area is needed to gather good and complete cost data, and to fill the gaps in understanding the costs of carbon mitigation options.

- Results showed that different strategies may be appropriate in different cities and hence demonstrated the need for policy at an appropriate scale (the urban level) to address air pollution mitigation including GHG emission reduction.

- Results confirmed the importance of the inclusion of health co-benefits in economic analysis of mitigation strategies. Options that may appear costly in terms of the financial cost may become viable in many cases when co-benefits are considered.

- Public acceptance of policies/measures is an important factor for their successful implementation. Citizens living in ICARUS cities have so far demonstrated a positive attitude towards proposed policy interventions. There were, however, a few measures dealing with pricing and restrictions or behavior change (transport modes, changing heating technologies, insulation in buildings), which are usually quite sensitive in terms of public acceptance, but have nonetheless generated positive reactions (Stuttgart, Milan, Brno, Madrid). Even

measures that are traditionally considered controversial can be implemented successfully, if they are built on stakeholder engagement from the initial phase of the planning process.

- With regard to socioeconomic differences citizens with low socioeconomic status (SES) are generally more likely to be exposed to higher levels of air pollution and they are less likely to take up new technologies which may be developed to improve life quality. Furthermore, they are less likely to participate in cultural activities and sport and generally travel shorter distances. On the contrary high SES groups travel by car more than low SES groups but this is not always the case and that choice of transport mode depends on local circumstances. In order to create healthy cities particular and to reduce health inequalities in cities attention will need to be paid to reducing exposure to air pollution and technology uptake by low SES groups, reducing car use in high SES groups and encouraging higher participation in cultural activities among low SES groups.

2.2 Recommendations for several activity sectors

Policies and measures for meeting environmental and climate aim should – at least in the long run - be efficient, i.e. the benefits should outweigh the costs

- Benefits include the reduction of damages and risks to humans, ecosystems and materials by reducing air pollution and climate change.
- Costs include financial costs (including capital costs and operations and maintenance costs) and other negative impacts including time losses or reduction of comfort.
- Comparing the economic value of such benefits and losses involves placing monetary values on these costs and benefits, where possible, and comparing them across time.

In general, in most cases in the ICARUS cities the benefits of mitigation actions outweigh the costs when health co-benefits are considered.

However, this is not always the case and different city level actions will be merited which consider factors such as differing baselines, different urban forms and differing priorities for citizens and policy makers.

- Fully integrated cross-cutting environmental policies are needed, which consider the multifaceted nature of “wicked” environmental issues. Climate mitigation policies cannot be made in a silo from air pollution, health and other environmental strategies.
- Policies and measures, that reduce greenhouse gas emissions, in most cases also change – reduce or increase – emissions of air pollutants and vice versa. Thus, if one department of an environmental authority prepares an air pollution control plan and another one a climate protection plan, inconsistent policies may arise. A combined, coherent set of environmental policies is needed to deliver optimal solutions for society.

The indicator that should be regulated to reduce the damage caused by air pollution should be the averaged exposure to the pollutants or the averaged intake by inhalation of the pollutants, and not the concentration at certain outdoor measurement stations.

- Health risks of air pollution mostly stem from the inhalation of pollutants. And by far the highest health risks are caused by the inhalation of PM2.5 and NO2 over a longer time period of several to many years.
- Thus the averaged exposure or intake over a longer time period should be used as indicator, as it is obviously correlated with chronic diseases and especially chronic mortality.
- Exposure means the average concentration of a pollutant in the inhaled air over a certain time period, intake is the amount (mass or number) of pollutants inhaled into the respiratory system during a certain period.

Strategies to reduce damages caused by air pollution can take advantage of novel sensor technology to improve the targeting of restrictions

- The technology around sensors is improving and becoming less expensive over time. Personal sensors, like those used in ICARUS, can give better indication of the exposure of individuals to air pollution and further use of these technologies may enable more targeted actions to reduce individual exposures. Increased use of sensors across cities will give better insights into where damages are highest and give a better case for action that traditional air pollution monitoring offers.

Indoor Air Quality: Lessons from ICARUS

- Indoor air pollution poses a significant health risk and policy action may be needed
- People in Europe stay most of the time indoors. The project results show that in Europe about 24% of the exposure to NO2 and about 45% of the exposure to PM2.5 are caused by indoor sources.
- Indoor air pollution arises both from indoor sources of pollution (including cooking and cleaning) and from air pollution that comes from outside.
- Actions to address indoor air pollution will include measures to encourage
    - Better ventilation (e.g. better standards for extractor fans or cooker hoods),
    - behaviour change for individuals and, potentially,
    - the use of smart monitors in homes.
- More investigation of particular sources of indoor air pollution, including the use of incense sticks and wood burning stoves, is needed. Actions should be carefully designed to avoid unintended consequences.
- Concentrations of PM2.5 and PM10 in underground train and metro stations should be regulated; The measured concentration of PM2.5 and PM10 are much larger in underground

train and metro stations than in urban street canyon stations. The high pollution is caused by abrasion processes. Thus, a reduction (e.g. use of filters) would be beneficial.

Future visions need to be developed to assist in developing appropriate strategies

- In ICARUS, we have shown the potential for developing city level actions based on visioning processes, which allow stakeholders to consider different potential futures and plan in different ways.
- The city of the future may look quite different from the city of today – and these futures may emerge sooner than expected. We have seen the effect of COVID on commuting – and as technology advances and our work lives change, so too will the demands society places on urban systems. Being prepared for change, and being proactive in determining the design of our cities to be adaptable to different futures, is important.
- Damages and risks caused by greenhouse gas emissions could be assessed by using worldwide marginal avoidance costs to reach agreed climate protection aims, especially the aim agreed during the 2015 United Nations Climate Change Conference, COP 21 in Paris.

Reduction of air pollution from outdoor sources

- For small wood and pellet firings the use of fine-dust filter should be mandatory. Furthermore in cities with larger NO2 concentrations the mandatory use of SCR filters or the ban of these firings should be considered.
- The emissions of combustion processes in larger stationary and in mobile sources are now well regulated. A problem remains: small wood firings (< 1MWth). They contribute efficiently to the reduction of greenhouse gas emissions, but the damage caused by emissions of PM 2.5 and NOx is larger than the avoided damges of climate protection. Wood and pellet firings also emit more NOx than gas or oil firings (as the latter use low NOx burners).
- Contrary to combustions processes, diffuse processes like abrasion processes, bulk handling, demolition of buildings a.s.o. are less regulated; reduction possibilities should be investigated. For example tyre and brake wear could be efficiently reduced by developing and demanding tyres and brakes, that last longer without worsening their grip.

Reduction of air pollution from indoor sources

- Important indoor sources in private households are passive tobacco smoking, cooking and frying, operation of open chimneys and older wood log stoves in living areas, burning of incentive sticks and all kinds of diffuse abrasion processes. Reduction possibilities should be investigated. For example, ban of incense sticks or regulation to use effective kitchen hoods.
- Road map towards cities that are climate neutral and without harmful air pollution

- The thermal insulation rate for buildings should be enlarged to around 3%/a of all buildings, that are now (2020) not renovated. For all buildings, that get new tight windows, inserting mechanical ventilation systems with heat recovery should be mandatory.

Reduction of GHG emissions

- A strategy to reach the climate protection aims would be to implement a tax per t of CO2eq to be paid for each t of CO2 eq emitted for all sectors The tax would increase each year by a certain percentage (e.g.3%/a) until marginal costs per t of CO2eq to reach the PARIS aims are reached in 2050. If costs decrease due to technical progress, the tax will decrease. The CO2 tax would also be levied from imports according to the CO2 eq emitted during production and transport, as long as the producing country does not raise an own GHG tax. For exports in countries without GHG tax the tax would be refunded. However, the authorities would have to finance research and development and market penetration of new products and might also have to finance the infrastructure needed for the new techniques (charging stations, hydrogen grids, ...)

- The development of not too expansive long-term electricity storage would be urgently needed. Furthermore, research and development concerning the conversion of electricity in hydrogen, methane and synthetic fuels and the transport of hydrogen is necessary. After a decision is made to use hydrogen, the natural gas grid should be enhanced to be able to transport hydrogen.

- The main problem with electricity production from wind and solar is that electricity is only produced, when the wind is blowing and the sun is shining. Especially the occurrence of dark doldrums, that could last for several weeks, is a problem.

    - Solutions are either the storage of electricity in long term storage systems or the conversion of water using excess electricity in hydrogen and then the conversion of hydrogen and CO2 into methane and/or synthetic fuels.

    - The final products can be much more easily stored than electricity. Both options are currently still very expansive and need further development.

    - The production of hydrogen is cheaper as the further conversion into methane and fuels. On the other hand the infrastructure for methane and synthetic fuels, is already available.

2.3 More specific recommendations for local authorities and decision-makers

From the analysis of the 9 ICARUS cities, more specific recommendations for local authorities and decision-makers have been delivered, also on the basis of feedback from citizens:

- Reduce traffic in favor of public transport and set-up of bicycle and pedestrian lanes.

- Enhance integrated spatial energy planning (e.g. for renewables and district heating).

- Create informative panels close to fixed monitoring stations showing real-time data to increase population awareness.
- Increase monitoring and modelling facilities, for instance through citizen science. Citizen science measurements are an inexpensive way to increase the number of measuring spots in the city and simultaneously increase awareness of air quality.
- Better distribution of traffic flow - including public transport, with a carefully considered plan for location of parking spots.
- Constitute subsidies for sustainable traffic.
- City authorities need to develop an awareness campaign programs on what citizen can do to reduce environmental impacts of their lifestyle.
- Restrict/ban of all or at least most polluting motorised vehicles from the inner ring area (e.g. city centre).

2.4 Other key messages originated from the ICARUS work

- Urban areas are responsible for a large part of air pollution and carbon emissions. It is therefore particularly appropriate to tailor environmental policy measures at the city level. Given the peculiarities of each city, different strategies in different cities may be appropriate.
- It is important to evaluate the impacts of measures aiming at carbon mitigation and air quality enhancement by considering the effect of these measures on as many actors as possible: private citizens, municipalities, the environment, as well as the general population.
- The 'health protection' framework should be as much as possible taken into consideration when designing and implementing air quality and greenhouse gas related policies.
- The Cost Benefit Analysis carried out in collaboration on policies selected at the participating cities shows that the benefits of air quality measures outweigh the costs in many cases, with most of them achieving a positive Net Present Value.
- Health co-benefits of the general population can be particularly relevant, and, often, measures that appear costly in terms of the financial cost per ton of carbon reduced become viable when health co-benefits are taken into account.
- With regard to long-term visions key messages include how to enhance modelling of ridesharing services in macroscopic travel demand models and the potential effect car/ridesharing services, especially in combination with autonomous driving, have on the number of cars needed. ICARUS showed that car/ridesharing can reduce the number of cars in cities drastically if no private cars are allowed, which would have a great impact to improve air quality. These results were also discussed in a local podcast and newspaper article about future transport scenarios, advertising and introducing the ICARUS findings to non-scientific communities.

- Cost Benefit Analysis is characterised by a certain degree of uncertainty. First, in the identification and evaluation of the impacts of the selected policies. Second, in the cost data used in the analysis. Third, in the monetary quantification of intangible impacts. To deal with this uncertainty it is important to perform sensitivity analysis. The results of our sensitivity analysis show that analysed measures are hardly sensitive to variations in the inputs.

- With regard to climate change future projections of extreme events of perceived temperature (considering both temperature and humidity) over Europe look different from what we expect for extreme events of temperature only. Northern European regions will be subject to heat stress conditions more than what we expected considering extreme temperature only.

- At the academic levels our results highlighted the importance of the humidity in determining future changes in heat stress over many EU regions and the fact that it is not sufficient to investigate extreme events of humidity and temperature separately to derive the composite effect.

- At the policy level our findings suggest to take into account adaptation strategies to heat stress conditions also over region never considered before: different maps of future heat stress under extreme conditions are provided under different emission scenarios (CMIP5 RCP4.5 and RCP8.5) in a multi-model contest and compared to maps of extreme temperature only.

- ICARUS long-term visions and transition pathways: Through employing a foresight approach, combining participatory workshops with local stakeholders, literature review and horizon scanning, we developed long-term visions (up to 2050) of smart, green and healthy cities. Drawing together the visions and other materials, it was possible to identify three distinct visions of future cities that would be broadly sustainable, smart and healthy:

    - Smart Tech City – has more emphasis on technology as a solution to environmental and health issues, with individualistic values being important.

    - Sharing Smart Communities – takes the community at the centre and considers interconnection to be an important driver for improved societies;

    - Connected Cobweb City – considers a more dispersed, individualistic society, with more of a balance between technology and socially contingent solutions to the challenges facing our cities

2.5 Key points for informative campaigns towards citizens for reducing exposure to air pollution

An immediate and effective way for reducing the impacts air pollution, is to develop citizen information campaigns, on how they can reduce their exposure to air pollution. This type of strategy, is able to deliver immediate results in reducing exposure and the related health impacts, before the implementation of other costly (in time and finances) policies and measures. Key recommendations given to citizens so as to reduce personal exposure include:

- Avoid physical activity in highly polluted areas.

- Be aware of local outdoor AQ levels and pollution forecasts. Follow advice from air quality regulators in relation to outdoor pollution levels. The use of the ICARUS App is a valuable tool towards this direction.
- Carry out physical activity in the early morning before rush hour and prior to higher ozone levels that occur in afternoon. Activities should be at least 400 m from main roadways to lessen pollution exposure.
- Keep microclimate conditions in homes under control by avoiding excessively high temperature and humidity.
- Clean the rooms several times a day to avoid a build-up of pollutants, both gaseous and in the particulate phase (open the windows for short periods at least 2-3 times a day for 5 minutes).
- Always use hood/fan suction when cooking and open windows to avoid increasing humidity. Clean the kitchen after cooking regularly.
- Always carry out proper and periodic maintenance of air conditioning systems especially if they are not functioning properly, because in this case they do not guarantee an adequate air exchange, allowing the penetration of pollutants from outside; maintenance must also include the replacement of filters thus preventing the cultivation of mold and bacteria.
- Immediately remove mold using bleach, in case they appear.
- Household cleaning products (including indoor deodorants and fresheners) in indoor environments should be used with great restraint because they contain organic volatile compounds that are released during their use. It is therefore advisable to use products that are less harmful to our health and the environment, such as vinegar and baking soda, for daily cleaning; it is advisable to never mix different products and to carefully read the instructions on the labels before use.
- Remove the carpets from the dwellings that are receptacle of dust, especially in case children or people prone to allergies.
- Use good quality vacuum cleaners that do not release dust when using.
- The burning of wood in fireplaces or stoves, without pollutant reduction systems, is a major source of emissions of air particulates and harmful compounds and there is no doubt that biomass domestic heating contributes a substantial share to the air pollution people breathe.
- Comply with the rules on smoking bans in all public settings, including workplaces and avoid smoking in homes and cars, especially in the presence of children and women in the city; limit the use of candles especially scented candles and the use of incense sticks.