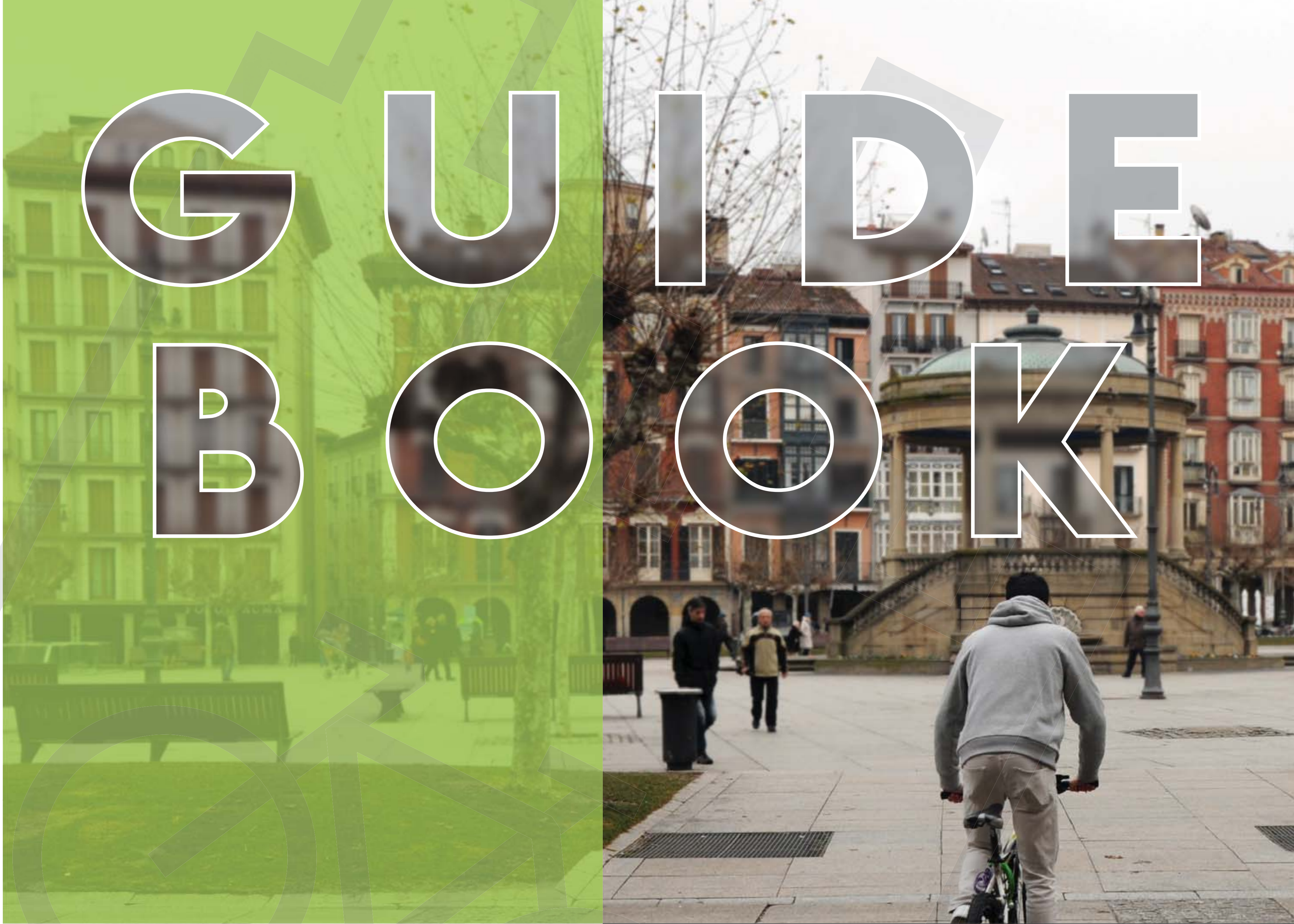
GUIDE BOOK



REDUCTION OF **EXPOSURE OF CICLYSTS** TO URBAN AIR **POLLUTION**

LIFE+RESPIRA

LIFE13 ENV/ES/000417

25 YEARS Life 1992 - 2017

With the contribution of the European Union's LIFE financial instrument

REDUCTION OF EXPOSURE OF CICLYSTS TO URBAN AIR POLLUTION

Editor

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INDEX

PREFACE
CONTENS

This book collects the main outcomes that were generated during the implementation of the LIFE+RESPIRA project (LIFE13 ENV/ES/000417), carried out in the city of Pamplona, Navarra, Spain. The research was conducted by a cross-functional team made up of more than 30 researchers belonging to three entities: The University of Navarra, the Centre for Energy, Environmental and Technological Research (CIEMAT) and Environmental Management of Navarra (GAN-NIK).

This book, which has been published in both Spanish and English, is divided into seven chapters:

1. Sustainable cities?
2. Exposure of citizens to air pollution.
3. The role urban vegetation plays on the quality of air.
4. High resolution models to assess air quality.
5. Impacts of urban pollution.
6. Urban sustainability and mobility.
7. Environmental communications and education.

This book aims to serve as a useful guide, providing a set of tools for scientists, managers and citizens, to improve the quality of life in our cities.

In addition, it intends to pay personal tribute to the cycling volunteers who participated in this project. They were the real creative force behind this, thanks to their wholehearted commitment for more than two years, providing us with a tremendous amount of data on air quality in the city of Pamplona. Our sincere thanks go to them.

THE LIFE+RESPIRA PROJECT

Cities generate a wide range of air pollutants, primarily related to the burning of fossil fuels (heating and motor vehicles). However, despite the major impacts on the climate and human health, we still lack large-scale systematic measurements of air pollution in cities, which ultimately leads to a misinterpretation of the actual state of urban air quality.

Given the continued growth of cities and the problems associated with traffic that arise as a result, development of new alternatives of transport is needed so as to improve air quality.

An effective way of contributing to urban sustainability is by encouraging the use of green transportation, such as bicycles. Paradoxically, this healthy activity could pose a risk to the cyclists themselves, due to their increased exposure to air pollutants emitted by road vehicles while commuting.

The LIFE+RESPIRA project seeks to shed light on these unknowns, demonstrating that by using new technologies and implementing new urban planning and design measures, as well as management of mobility, the exposure of cyclists and pedestrians to air pollution can be reduced.

In addition to this general objective, LIFE+RESPIRA has the following specific aims:

To measure the levels of pollutants inhaled by cyclists in real traffic conditions during their daily commute and evaluate the potential risk on their health.

To monitor the effectiveness of the implementation of certain cutting-edge technologies in real-life conditions and to obtain transferable conclusions which can be applied to other cities with similar characteristics.

To develop a mathematical model that allows extrapolating the results in order to improve the air quality control strategies and to contribute to the development of sustainable cities.

To compile small-scale pollutant distribution maps, close to real conditions, which aim to improve urban planning and management in different areas.

To develop a route planner which allows citizens to choose the healthiest route in terms of the current level of air pollution.

To assess the environmental, social and economic benefits of using bicycles as a means of transport in the city.

To engage citizens through an outreach campaign into the project development, making them the main drivers and enabling consciousness about their responsibility in air quality and in their own health.

To inform and educate and raise awareness about the air quality issues, promoting the development of more sustainable cities.

Jesús Miguel Santamaría
(Editor)

1. SUSTAINABLE CITIES?

Urban Life and Nature: a cultural interpretation of the LIFE+RESPIRA project

The urban and the natural - both distant and yet inseparable

When you compare urban life and nature, they seem two spheres of reality very distant from each other at first sight. The distinctive perception of urban life is a built-up urban area, or an agglomeration of different levels of density, with a diverse range of buildings and infrastructures. In contrast, in the environments that we consider natural, the human trace tends to decline, or even disappear as we see in natural forests (Fig. 1).

However, the animal-like, corporeal aspects of human beings and the influence we have on the environment encourage us to treat these two spheres of reality as intertwined. The urban environment depicts one of the most characteristic results of the collective activity of contemporary human beings. More than half of humanity lives in cities. Nature on the other hand, reminds us of our fundamental roots as human beings and our constitutive animal-like architecture. It reminds us of the integration into ecology, where people are dependent on ecosystem services for their daily means of support and well-being (either directly or indirectly). In addition, the particular way we have chosen to use nature up until now has carved out the landscape that we see today. The environmental impact that they uncover, calls for a closer inspection into the leading way of life and social and territorial organization, eminently manifested by the city.

Both consciously and unconsciously, humans have chosen to interact with the natural environment in a way that often threatens it, as is exemplified in the well-known deforestation suffered by the Amazon Basin (Fig. 2). This is partly due to the production of livestock feed, for animals that are to be fed around the entire world. For that reason, one can say that humans can literally 'eat the Earth from multiple urban environments. The consumers are oblivious to effects, which are sometimes even irreversible.

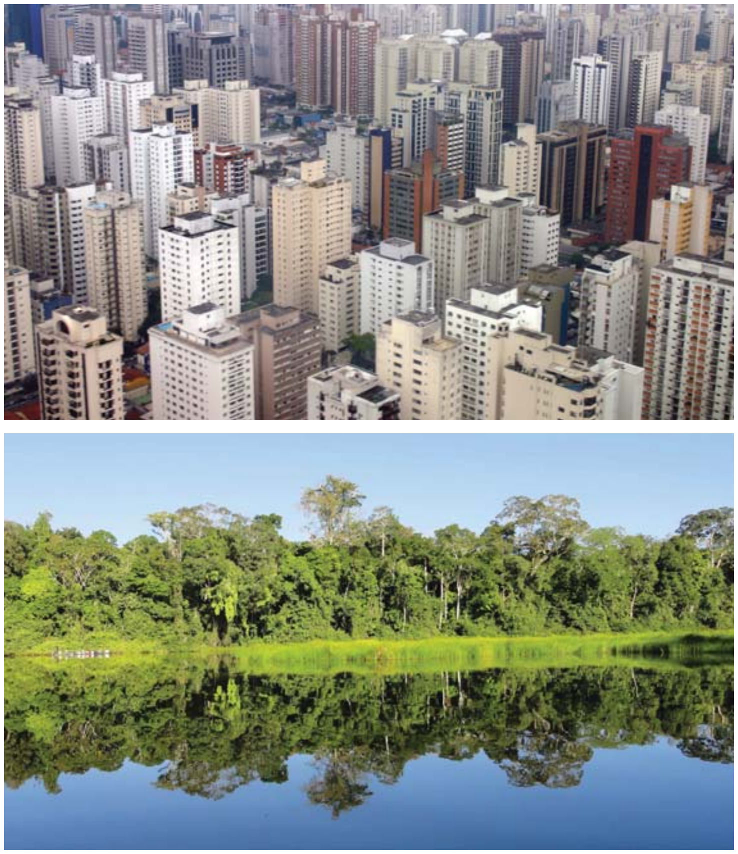

Figure 1. The urban environment and the natural environment.

Figure 2. A dimension measurement of the deforestation processes in the Amazon.

[1] https://data.worldbank.org/indicator/SP.URB.TOTL.IN.ZS

Figure 3. The hunter-gatherer, a being encompassed into the natural environment.

Figure 4. The fertile crescent of Mesopotamia represents early urban phenomena which were closely linked to agriculture.

Our life-style choices governed by the city lifestyle have led to serious, collective implications which have been overlooked so many times in urban life. One might wonder how we got to this - how our decisions have led to such stern effects on the natural surroundings, on which we rely, and to which we owe our ethical conduct. We may also wish to spread a culture of environmental respect which rethinks how we should be living in this day and age (mainly in the cities).

Our awareness of the natural human nature seems to have faded over time in urban cultures. It is apparent when we look at the way that humans lived in the hunting-gathering period (Fig. 3).

The agricultural awakening offered the possibility of accessing and storing ever-increasing amounts of food, through harvest and trade. A new urban-culture settlement was developed, which was directly supported by agriculture. It is symbolised by civilisations as diverse as the Mesopotamian (Fig. 4) or those associated with the rise of the Greek culture. For centuries and millennia thereafter, cities continue to be closely linked with agriculture. These are still home to the minority of the Earth's population, with the majority living in rural areas, or closely attached to the land, living in relative harmony with the natural environment.

Things change from the 18th - 19th centuries. The Industrial Revolution brings about rapid depletion of copious amounts of natural resources, which are forgotten to be replenished (Olsen and Galimidi, 2009). With this, a new type of city emerges, portraying the urbanisation we see today with two attributes to be highlighted: the first being that the urban phenomenon is gradually spreading across the entire planet, where it is hosting increasingly more and more humans, affecting it more and more on a global level. The second feature is that the population is growing more in the poorer countries. They have been amassing the biggest increase in urban population in the last decades.

Some of the cultural and environmental implications of urban life

As the urban phenomenon spreads across the Earth, together with its lifestyles, the city's inhabitants become exposed to a certain disregard to nature, as Aldo Leopold, (an American environmentalist) states in a literary, yet rather unsettling way:

"There are two spiritual dangers in not owning a farm. One is the danger of supposing that breakfast comes from the grocery, and the other that heat comes from the furnace" (Leopold, 1949).

This oblivion is apparent from the outset. The ever-increasing urban environments disregard the presence or status of things natural. At the best, nature is reduced to decorative green areas in the form of parks and gardens in the communities that can afford them. The oblivions are also evident in urban areas which maintain unsustainable ways of living at the expense of a loss of natural value elsewhere – out of site, which detaches them from the reality of what it really entails.

This damage is caused by business freight connections, which are difficult to envision on a day-to-day basis no matter how much they grow or assure daily supply. Few of the city's inhabitants even realise that their own houses for example, were made from the material extracted from the unsightly quarries they may be deploring close to their homes. As the urban way of life continues to grow, the sense of belonging to the land is easily lost and this estrangement with nature becomes more and more apparent. Citizens are losing their bond and affiliation with nature and as a result, often unintendedly act according to the words of Leopold:

"We abuse land because we regard it as a commodity belonging to us", (Leopold, 1949).

The results on culture are truly worrying. In other words, from the same author, now a big name in environmentalism:

"We end, I think, at what might be called the standard paradox of the twentieth century: our tools are better than we are, and grow better faster than we do. They suffice to crack the atom, to command the tides. But they do not suffice for the oldest task in human history: to live on a piece of land without spoiling it" (Leopold, 1938).

The current land-use patterns amount to an overall loss of the Earth's natural value. However, the value that is taken from nature to shape the distinguished urban culture that we see today, is never restored to the natural world, and no attempt is made at doing so.

The natural foundation that allows for the very birth and existence of the human race is facing increased prospects of deterioration, in the shape of pollution or a progressive and irreversible loss of a growing number of resources or natural assets, which will disappear forever. The loss of species and irretrievable degradation of land confirm this. Urbanisation, including the more privileged cities from an environmental point of view have such impacts, not only in particular nearby places,

Figure 5. Urbanisation has an impact on the planet in ways that are not always obvious.

Figure 6. Social exclusion cityscapes.

but also in far-away, wide-spread places all over the planet (Fig. 5). This is evident when you look at for instance greenhouse gases emissions and global warming over the last decades.

The already-anticipated characteristics of the contemporary urban phenomenon also show to have an uneven distribution of wealth within the cities, including environmental quality.

The development of social polarization within urban landscapes has risen in the last decades, creating landscapes of outcasts (Fig. 6), with poor access to commodities and a lifelong, high exposure to unhealthy environments.

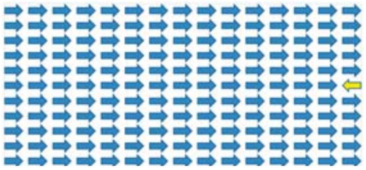

Figure 7a. Making a choice in a pluralistic society.

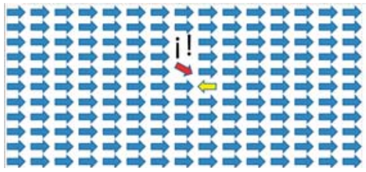

Figure 7b. Change can cause concern and apprehension.

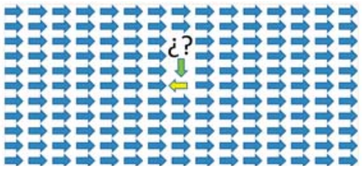

Figure 7c. A difference in opinion or behaviour raises questions.

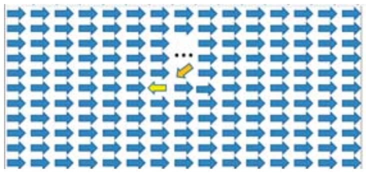

Figure 7d. Progress toward voluntary membership

The response of the LIFE+RESPIRA project

The outlined challenges cannot be resolved by one project alone, but it can however address them, taking on a wider perspective, which the LIFE+RESPIRA project has done from the outset. It strives to make the biggest possible contribution, no matter how modest or limited the public outreach may be, in order to generate the necessary shifts in culture to move towards a sustainable future, which is still beyond the horizon. With that in mind, the project does not seek to offer a single global solution, but rather to become an extension of the essential framework, which must be approached collectively, little by little and always tackling the deep, common roots of the difficulties we face.

The cultural and ethical challenges that the project proposes, through its specific pollution, mobility and health-related goals, is to encourage the restoration of greenery and respect for nature into the way of life of urbanized societies. The idea is to open a gateway to nature in the city, but also in direct line with the project in question, to open the lifestyle to search and find humankind's natural self. In order to discover it, the project will question itself in its specific area, investigate pollution in relation to urban movement, thereby laying down the foundations for a reasoned and reasonable call to improve the design of the city and the mobility behaviours that are preventing us from leading full and healthy urban lives. The aim is to ultimately act in accordance with our way of being, not only in terms of culture and citizenship but also in an ecological and natural way.

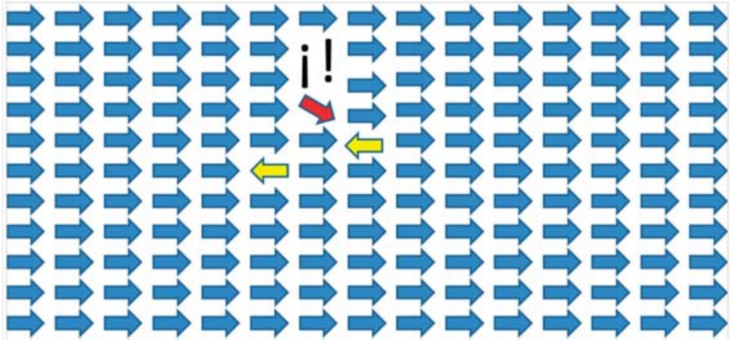

Figure 7e. In democratic societies, social change must start with the individual. Commitment must be freely entered into and expressed at will.

But it's not easy to halt and reverse trends. Neither is it easy to motivate yourself to cycle in a place where the majority of the population choose other means of transport, such as cars, which so often clash with bikes. Or, all too often (and justifiably so), when cyclists violate rules and show uncivil behaviour. But on reflexion, leaving aside these unwanted attitudes, bikes have a lot to offer, not only in terms of mobility, but also on the very basis of the urban way of living and the need for improvement. The way forward may stipulate going against the grain, increased coherence and avoiding as much as possible to stand out unduly or imposing on anyone while doing so (Fig. 7a). If you were to rightfully propose someone change their deep-rooted behaviour, it´s likely you would be faced with indifference or a lack of response – or even concern or apprehension (Fig. 7b). Our hope is that these proposals are met with respect, that apprehension is turned into curiosity and that this behaviour is questioned and reflected upon – or even changed, which in turn tends to lead to the word being spread (Fig. 7 c, d, e).

The tools used in the entire development of the LIFE+RESPIRA project are fruits of these fundamental beliefs. Together with the scientific objectives, social goals have similarly been addressed. It has therefore managed to bring together a highly qualified and specialised study as well as active involvement of citizens, which was essential for the project. In turn, this social aspect served as a constant target for the project, constantly reminding the participants of its citizen science essence: to research for society, counting on it from the very start and through its entire development.

This is reflected in the interdisciplinary approach (bringing together experimental and social sciences, technology, education, and communication…) and also the careful, well thought-out research design, to highlight the vital roles of the citizens, which we also wanted to promote. The vast amount of data collected by all kinds of participants laid the foundations for the painstaking processing and the highly technical and specialised analysis that ensued. The results have begun to emerge, already having an impact on the intended citizens and their elected representatives, nourishing their decision-making and accomplishing an emerging emulation effect, (which cannot be planned), beyond the immediate territorial scope of the project (Fig. 8). The developments in the project are already spreading to other urban environments that request the LIFE+RESPIRA team's help from the experienced gained.

Change on the horizon

Going back to where we started, it's still too early to observe changes in trends in our society moving forward and leading more natural lives in the urban environment without having such an impact on it. Especially if you take into account that some of the unsustainable behaviours that we see today might have originated a long time ago, and be firmly rooted, which leads to inertia, a continuance out of pure habit and that isn't the right way forward. This is demonstrated in the path we have taken over recent centuries, for instance the carbon footprint we have left from burning fossil fuels locally (Fig. 8). It is alarming to see that our culture has become so used to accepting that the damage caused to the Earth is something inevitable, something that amasses, even though we are worried about the unforeseeable damaging effects or the unpredictable consequences that are even more difficult to evaluate.

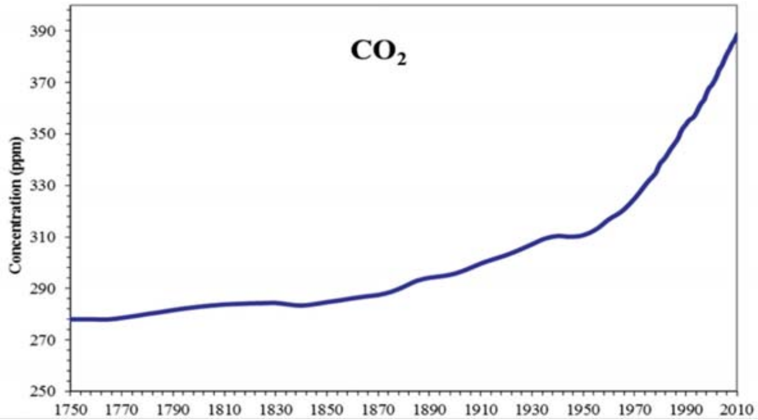

Figure 8. The origin and evolution of the increase in levels of atmospheric carbon dioxide.

If we look beyond the specific proposals set out by the project (proposals of behavioural changes with regards to transport and mobility in Pamplona, changes to city life or redesigning spaces), LIFE+RESPIRA manifests a more universal response and it does so with an implicit, yet fundamental ethical approach and shared by all: "Depleting the Earth´s natural resources to feed our need for luxury, or revelling in the benefits at the expense of causing damage elsewhere, thus denying the people in those areas the right to a natural and human life is not worthy of being called human. This conduct should be dealt with step by step until it is completely reversed".

The LIFE+RESPIRA Project aimed to promote a culture which invites dialogue between people and societies and encourages commitment to work together to create an improved, natural and cultural environment. Researchers, institutions and citizens gathered to engage in studies about how we are impacting others and the environment. The idea was to act on the findings, promoting greater respect for the ones who suffer. It is key we continue with this endeavour, bearing in mind the challenge of managing to bring about significant and lasting cultural change.

"...also, the things that do not prevail in this lifetime live on like a dynamic force, and it is precisely those ideals that do not come to fruition that reveal themselves to be invincible. Just because a dream hasn't been fulfilled, it does not mean that it was wrong or obsolete; and a need, even if hindered is no less necessary. Only the ideals that have not been realised live for us when we are gone, impacting the future generations like a moral impulse" (Zweig, 2005).

References

Leopold, A. (1938). Engineering and Conservation. In C. MEINE (Ed.), Aldo Leopold. A Sand County Almanac and other Writings on Ecology and Conservation. (ed. 2013). New York, Library of America, 405–410. p. 410.

Leopold, A. (1949). A Sand County Almanac. New York, Oxford University Press.

Olsen, S. and Galimidi, B. (2009). Managing Social and Environmental Impact: A New Discipline for a New Economy. Brown Journal of World Affairs, XV (II), 43-56. Consultado el 14 de octubre de 2014.

http://svtgroup.net/wp-content/uploads/2011/09/Managing-Social-and-Environmental-Impact.pdf

Zweig, Stefan (2005). "Erasmo de Rotterdam. Triunfo y tragedia de un humanista". Paidós 2005, p 201-202.

2. EXPOSURE OF CITIZENS TO AIR POLLUTION

The exposure of cyclists to urban pollution

This chapter deals with the management of and experiments carried out with the integrated sensors used by LIFE+RESPIRA to measure gases and particles. In order to obtain a fine-scale assessment of air pollution, this project combines three concepts: integrated sensors, citizen science, and big data management. The project relied on a group of active volunteers, who transported 50 pieces of sensor equipment analysers in their daily commutes by bicycle. The generated data has been combined into one single database with 13 million samples (5 million of which were used in the analysis). They were taken from 62,000 km of journey distance over the course of two years. The long-term archiving and the access of the generated data are handled by the European EUDAT platform (https://eudat.eu/).

Design and methodology of the data collection

Unlike the usual practice, with continuous series of sensor data from known, fixed positions (e.g. Borrego et al., 2016), LIFE+RESPIRA draws its knowledge of atmospheric pollution on a fine-scale level by assembling a large sample of data, using continuously-geolocated, mobile sensors which are on the move, spread out across the city of Pamplona (Fig.1). Thanks to the high sampling rate, we managed to obtain a resolution of only a few metres, which enabled us to position the set of samples on a map and get a range of information to be able to answer the researcher's questions.

Figure 1. Cycling on a bike path with the analyser in its usual position - in the basket.

Operation of the sensors

The portable analysers that were used were prototypes assembled by the company KUNAK according to specifications set by LIFE+RESPIRA (Fig. 2). We combined the use of electrochemical sensors and optical particle counters (OPC), supplied by Alphasense (Alphasense, 2015), a GNSS receiver which is able to detect the GPS and GLONASS constellations and carry out EGNOS corrections, temperature and humidity sensors, and a GPRS unit that communicates with the cloud on the Internet, which is where LIFE+RESPIRA gathers the data through the platform's API.

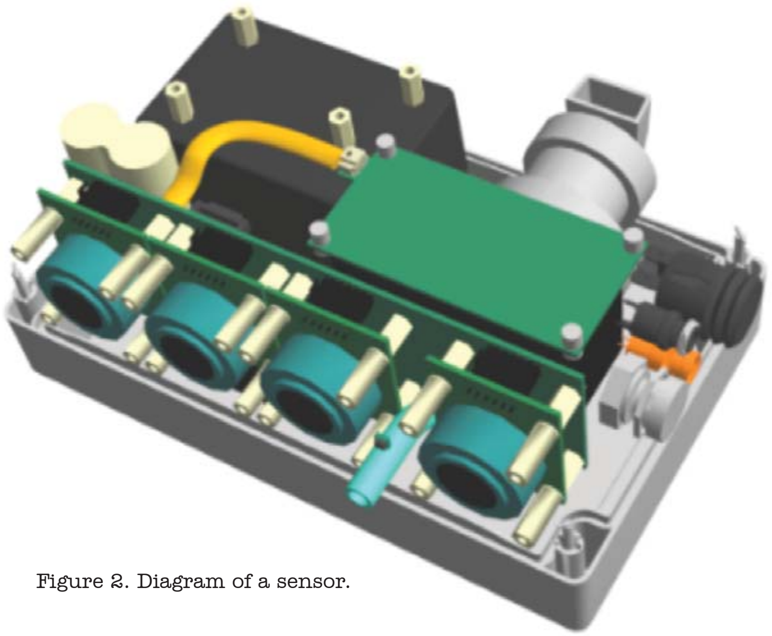

Figure 2. Diagram of a sensor.

The four electrochemical sensors used in LIFE+RESPIRA belonged to Alphasense's B4 series, which is suitable for measuring gases at low concentration. Installed sensors were for carbon monoxide (CO), nitric oxide (NO), nitrogen dioxide (NO_2), and oxidants. The later sensor yields ozone (O_3) readings by subtracting the level of NO_2 from its signal.

The integrated OPC built in some of the analysers detected three types of atmospheric particulate matter (PM) according to size: PM_1, $PM_{2.5}$ and PM_{10}. In addition to the gas and particle signals, other basic signals were also recorded, such as temperature, humidity, GPRS signal strength, satellite geometry, etc. Typically, five readings are made per second, which are averaged every ten seconds. The data accumulated in the analyser were transmitted in bulk every half hour via the GPRS network together with the geographical position of the sensor during the readings. On average, each data point corresponds to the state of the atmosphere in an approximate 40-metre segment that the cyclists typically travelled from one point to the next.

Sensor Deployment

The project provided 50 analysers, each containing a sensor suite, that the volunteers reserved online using an application and then borrow from the project, much in the same way you would borrow a book from a library.

Each analyser had its own QR code in order to assist the loan and to enable tracking and status control. Volunteers scanned the QR codes on collection and return of the analysers (Fig. 3) so the analyser was attributed to the volunteer during the loan. Some volunteers also wore a heart rate monitor in order to indirectly estimate the effort and the volume of breathed air while cycling. The analysers were placed in baskets, which were then attached to the bicycle (or also in rucksacks or on the roof of a car) and sensed gasses as they moved about.

Some analysers were also positioned in fixed monitoring sites for continuous operation. They served to intercalibrate with official benchmark sensors and among themselves (Mead et al., 2013).

Figure 3. Sensor control panel and a volunteer with a sensor.

LIFE+RESPIRA - GESTION DE CAPTADORES

Seleccionar el captador que se va a gestionar

Actualización: 25/02/2016 0:13
Actualizado cada 5 minutos

En caso de duda, llamar al 948425600 extensión 802396

Ciencias ▪	Civican ▪▪▪▪	Mendillorri: No qued	Condestable ▪▪▪	Prestados: 50%
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1 - RETIRADO	2 - PRESTADO jjmirujo	3 - PRESTADO artarip	4 - TRASLADAR artarip	5 - PRESTADO aperezdezab
6 - PRESTADO rberord	7 - DISPONIBLE Iturrama	8 - PRESTADO guerreroaspurz	9 - PRESTADO oraintxe	10 - DISPONIBLE Condestable
11 - RETIRADO	12 - DISPONIBLE Condestable	13 - DISPONIBLE Condestable	14 - PRESTADO manuel.serrano1239	15 - DISPONIBLE Jus la Rocha
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21 - RESERVADO stainta	22 - DISPONIBLE Civican	23 - PRESTADO Lpiedrag	24 - DISPONIBLE Amigos	25 - RETIRADO
26 - PRESTADO jaarbilla	27 - DISPONIBLE Amigos	28 - DISPONIBLE Ensanche	29 - PRESTADO inaki.arbilla	30 - PRESTADO artarip_park
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36 - PRESTADO iciscar	37 - PRESTADO fgil	38 - PRESTADO mbarnole	39 - PRESTADO tintxo5	40 - PRESTADO alberto.berrueta
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46 - RETIRADO	47 - RETIRADO	48 - RETIRADO	49 - PRESTADO luislavin	0 - RETIRADO

Clave de situaciones	
Prestado	En manos del voluntario
Disponible	En el centro de reparto, disponible para préstamo
Cargando	En el centro de reparto, puede prestarse pero puede faltarle carga
Reservado	En el centro de reparto, hay una reserva sobre el captador
Trasladar	Está fuera de su sitio o debe ir a calibrar
Retirado	El equipo no está disponible

Data Collection and Storage

The LIFE+RESPIRA project generated a substantial amount of data. Tuples containing a timestamp, sensor identification, parameter label and raw sensor data were streamed to the company's platform. A number of applications running in the project's workstations and servers harvested, processed and tabulated the data, collecting them onto a main database (VFP9). Other routines and applications queried the database and extracted filtered and combined records for further analysis (Fig. 4). We used custom-made programs, routines and algorithms written in R, VFP or Python for bulk processing and subset generation. This workflow enables end-user analyses can to be carried out using common platforms and application suites such as e.g. Excel, PowerPivot, or QGIS working on extracted subsets.

As data from the sensors were labelled with a timestamp and a geographical position, they could be matched up with other data from the heart rate monitors, the climate variables provided by the meteorological service, and the official data of air quality issued by the Government of Navarra (http://www.navarra.es/home_es/Temas/Medio+Ambiente/Calidad+del+aire/) for co-located sensors. Prior to the matching, adjustments were verified experimentally, for example compensating for any lagging or time differences between the services.

The data generated, as well as the majority of the analytical products (mainly air pollution maps, segmented according to various criteria) were uploaded to the European EUDAT platform for long-term archiving. A pilot project of EUDAT called PAIRQURS *(Public Access to Air Quality Urban data from Roaming Sensors),* enabled the creation of a data flow so as to facilitate the storage and permanent archiving and also release the result for public use. PAIRQURS monitors the LIFE+RESPIRA project's results and it generates a permanent record and archives a copy on the EUDAT servers when it detects new products available. It also has a comprehensive set of metadata that describes the products according to a schema created specifically for LIFE+RESPIRA. These metadata allow other researchers, the public or other applications to locate the appropriate files that are needed to be used from thousands of other generated files.

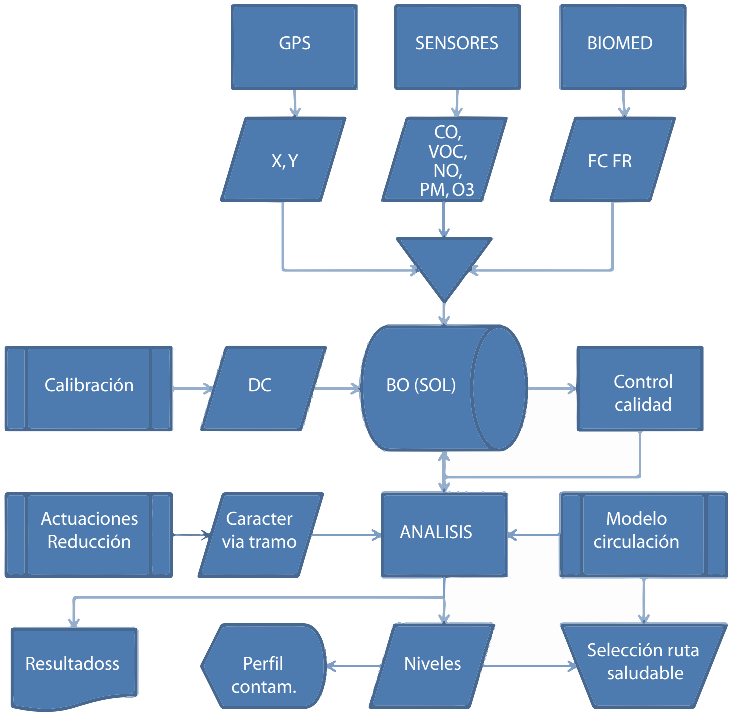


Figure 4. Flow of data generated by the sensors.

Results

Facts and figures from the project

The main data collection began in May 2015 and lasted for 24 months (Fig. 5) followed by data collection on a smaller scale, for specific experiments, filling gaps or verifying results.

The main collection had yielded the following results as of December 2017:

Volunteers	200
Journeys	20,000
Km (travelled by bike)	47,000
Km (motor vehicles)	15,000
Hours in motion	16,000
Journeys with biometric data	1,500
Hours of data collection	77,000
Samples with measurements	1,463,090
Geo-localised spots	4,155,131

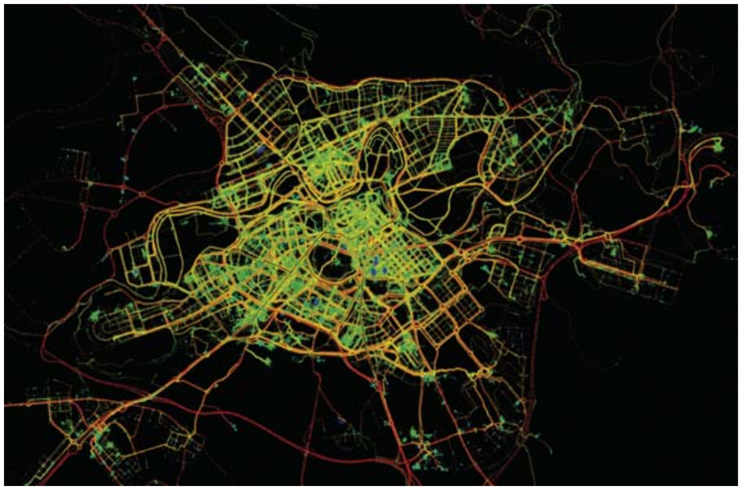


Figure 5. The positions of the spots with data draw a recognisable map of the city. Here, the colour represents the average motion speed.

Technology development

Measuring low-level pollutants to a fine-scale with mobile air quality sensors is challenging because at low gas concentrations, the applied technology and the sensors exhibit poor signal-to-noise ratio and high sensitivity to interference (Mijling et al., 2017). This was a pervasive issue in our project since simple calculation functions were unsuitable for the weak signal available in the majority of the samples. Furthermore, we observed scant robustness and reproducibility despite being considered among the most reliable low-cost sensors available on the market (Afshar-Mohajer et al., 2017). As the project amassed a vast amount of data, processing by suitable big data techniques allowed for the use of distribution statistics to isolate the signal, but only after very significant effort was dedicated to develop calibration and correction techniques and algorithms to improve its reliability. For example, we developed variance filters with the aim of eliminating capacitive interferences that affect some of the sensor's electrodes (Fig.6); experimental protocols to attain the calibration parameters or to estimate the interference between gases; detection routines for time delays with the official data in co-location experiments; or statistical models to enable an even more precise adjustment of the calibration parameters than those available from the manufacturer.

Many of the detected errors proved impossible to correct, and such data was therefore conservatively marked as potentially invalid. This affected more than half of the total number of records in some way. Some examples included: OPC sensor errors due to air flow perturbation, which meant that we had to discard the samples of particle data that were taken above a certain speed threshold; unexplained, synchronized temporary loss of sensitivity across sensors; non-linear interference of the sudden variations of temperature and humidity (Fig. 7); GPS signal obfuscation at certain times; nonlinear phenomena such as the coalescence of gas bubbles at the free surface of the electrochemical sensor's auxiliary electrodes, etc.

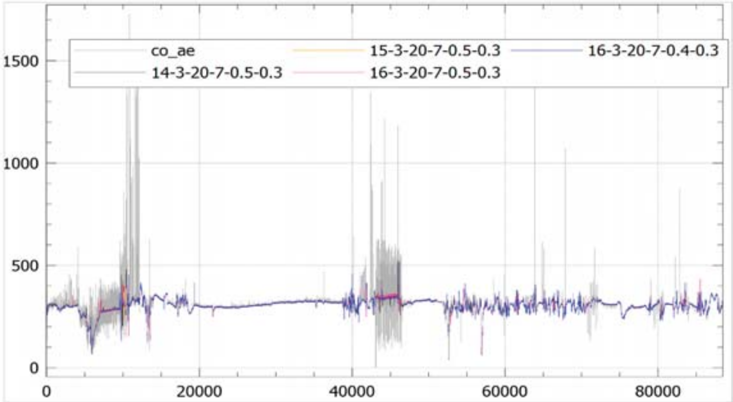


Figure 6. Original signal of one of the electrodes of the CO sensor (in grey), processed with various filter settings to detect interferences.

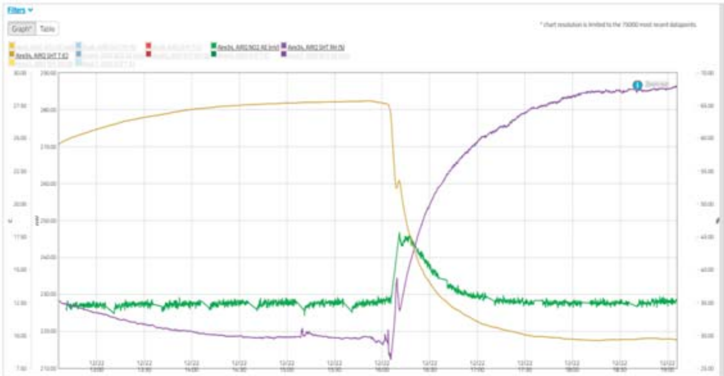


Figure 7. The effect of a sudden change in relative humidity (purple) above the NO_2 sensor signal (green).

After developing appropriate techniques we were able to improve the signal quality and the intercalibration of sensors by approximately one order of magnitude (Fig. 8). The combination of analytical refinements, calibration experiments, and the availability of a very large mass of data may thus allow for the use of these low-cost sensors for a fine characterization of contaminants in the environment. However, if one of these three factors is missing, the signal may be too weak or erratic to be reliable.

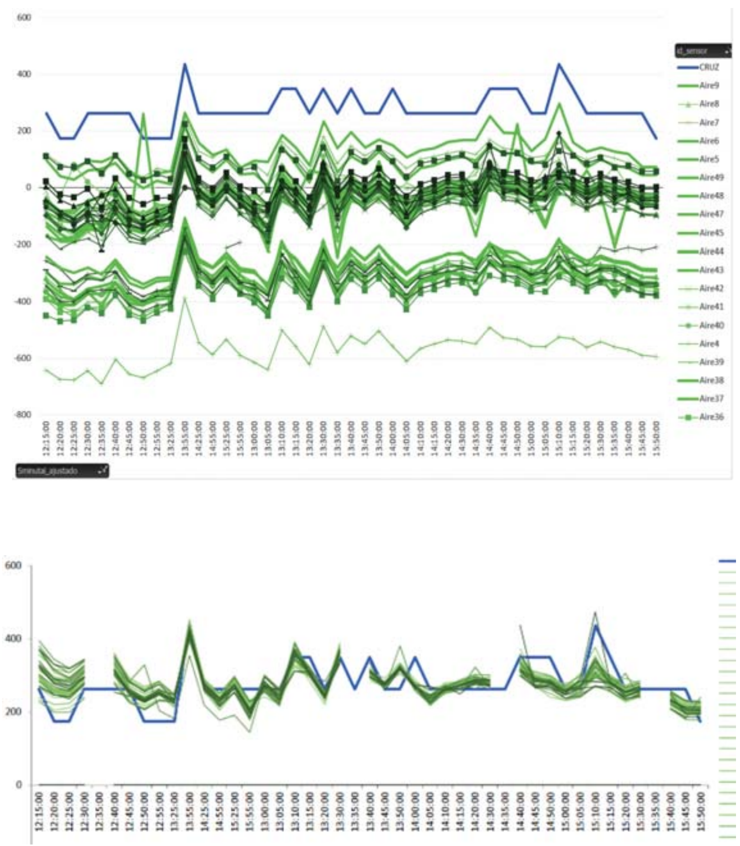


Figure 8. The co-localised sensor readings for a single contaminant before and after the final phase of the intercalibration corrections. The blue line is an official reference.

The distribution of pollution in the city

The study, which was conducted in the city of Pamplona over the course of two years allowed us to observe the pollution at both coarse and fine resolution. Across the board, the distribution of pollutants was strongly linked with the emission sources (mainly traffic) and their temporal variations, and to a lesser degree the weather circumstances and topographic layout of the city.

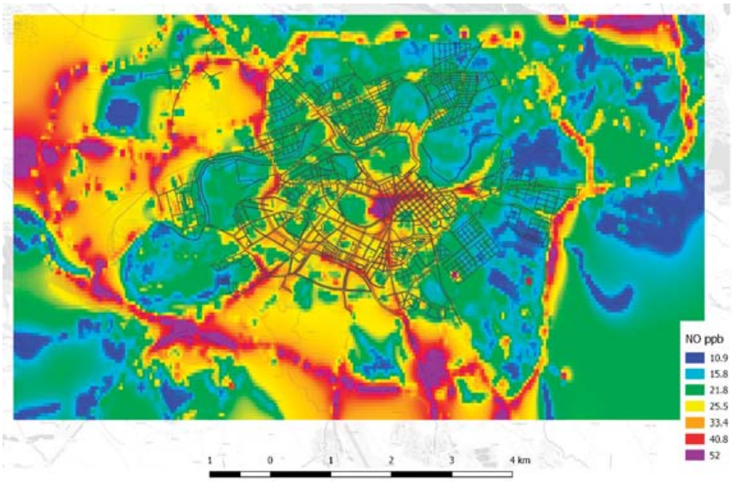


Figure 9. The average concentration of NO during the two years of measures. The areas with the highest concentration correspond to the major motorways and to the bus station, where a large number of diesel engines are concentrated.

The concentrations of nitrogen oxides (NOx) were remarkably high, both in heavy traffic routes as well as heavy vehicle concentration points, equipped with diesel engines, which was one of the main sources (DEFRA, 2017). An area where a high level of pollution was detected was paradoxically next to a park—but it can be attributed to the ventilation ducts from the main bus station, located underground in the city centre (Fig. 9). There was also a visible difference in the level of air pollutants when we compared the more transited routes with the less transited ones. Congested routes consistently showed higher concentrations (Fig. 10). This correspondence has also been noted in other cities at a lesser spatial resolution (Borrego et al., 2016; Guerreiro et al., 2013). In the most polluted places, and in particular during peak hours, the levels can be consistently higher than the hourly standards set out by the European Commission. Other observed features include short-space gradients between main roads and parallel, but separate lanes and pavements. The interior of parks and gardens showed significantly lower pollutant levels

Traffic speed was correlated to pollution levels: faster roads had higher levels than limited-speed streets, although evident point concentration of pollutants was recorded at traffic lights, crossings and roundabouts.

The prevailing wind, normally a dispersion agent, can also cause local accumulations, which direct the pollution from fixed sources to concentrate in stagnant areas. Our data shows that in the city of Pamplona, there was a higher concentration of carbon monoxide in the industrial belt, located in the north of the city, which tends to amass in its northwest area: a lower area situated windward at the foot of the city, in a small plateau, which could hinder dispersion (Fig.11). Comparably, the outlying residential areas showed lower concentrations of this pollutant.

However, in winter, these same residential areas show a high concentration of particles, probably associated with household wood-burning chimneys, from the prevalent detached and semi-detached home constructions in those areas.

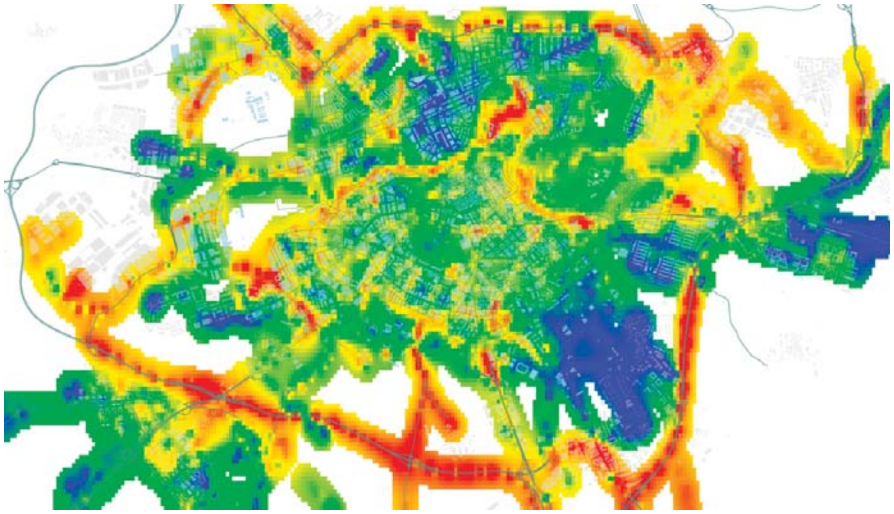


Figure 10. The average levels of NO_2 on a scale from blue (low) to red (high) between 8:00 and 9:00 in the morning. The highest levels correspond to the routes of heavier and faster traffic, such as bypasses or main axes with several lanes. There are points of high concentration in crossings and some schools. Levels of ppb above 40 (an indicator of poor air quality) are shown in red.

Figure 11. Concentration of CO. The highest levels (indicated in red) correspond to the stagnant areas next to the NW slope of the city, while suburban neighbourhoods have lower concentrations (indicated in blue).

On a fine scale, there were consistent differences in the levels of pollution between the road and the bicycle paths or sidewalk pavements (Fig. 13), which is probably consistent with the dispersion patterns of the plumes produced by emitters (traffic for NOx). Travelling on the road leads to an increase of between 37% and 54% of inhaled nitrogen oxides compared with using the bike lanes or sidewalk pavements (when permitted). The ozone changes only 5%, but the air around sidewalk pavements and bike lanes contained 90% fewer PM_{10} particles and 52% fewer $PM_{2.5}$ than the air on the main axis. On the other hand, carbon monoxide was less important along the road axis. It should be noted that emissions of this pollutant by current-technology engines is highly controlled by e.g. catalysers, and is no longer a significant marker of traffic pollution but of other, fixed urban sources.

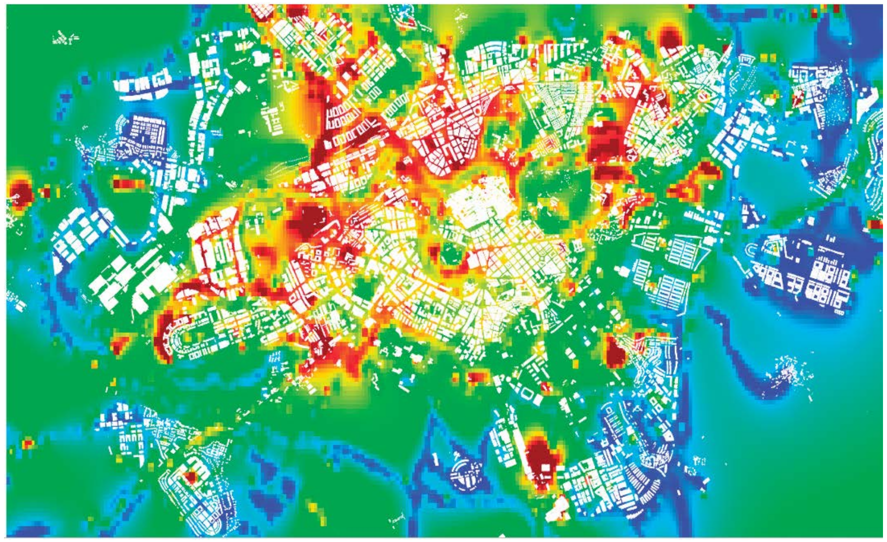


Figure 12. Average levels of fine particle matter, $PM_{2,5}$.

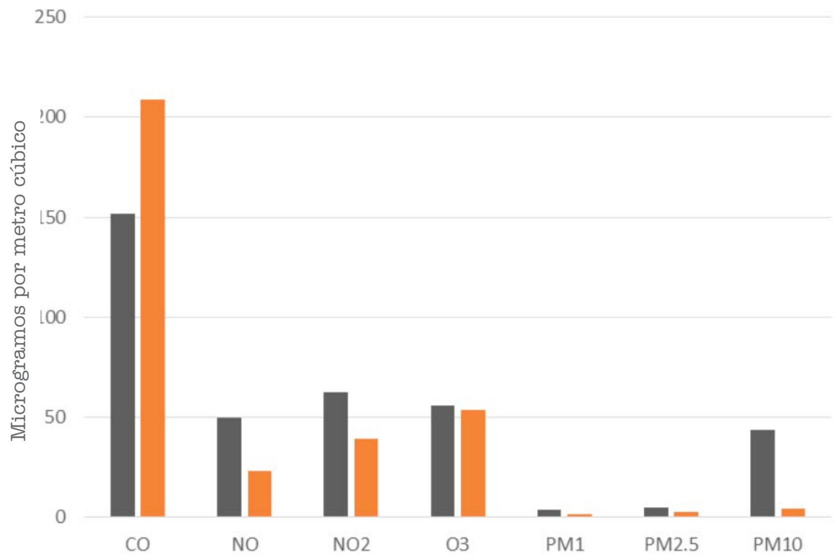


Figure 13. A comparison of the levels of air pollution between the bike lanes, roads and sidewalk pavements (figures in $\mu g/m^3$).

References

Afshar-Mohajer, N., Zuidema, C., Sousan, S., Hallett, L., Tatum, M., Rule, A. M., …, Koehler, K. (2017). Evaluation of low-cost electro-chemical sensors for environmental monitoring of ozone, nitrogen dioxide and carbon monoxide. Journal of Occupational and Environmental Hygiene, 9624(November), 0–0. https://doi.org/10.1080/15459624.2017.1388918

Alphasense Ltd. (2017). OPC-N2 Technical Specification, 44(0). Retrieved from http://www.alphasense.com/WEB1213/wp-content/uploads/2017/05/OPC-N2.pdf

Borrego, C., Costa, A. M., Ginja, J., Amorim, M., Coutinho, M., Karatzas, K., …, Penza, M. (2016). Assessment of air quality microsensors versus reference methods: The EuNetAir joint exercise. Atmospheric Environment, 147, 246–263. https://doi.org/10.1016/j.atmosenv.2016.09.050

DEFRA, Department for Environment Food & Rural Affairs, & Department for Transport. (2017). Improving air quality: national plan for tackling nitrogen dioxide in our towns and cities - Defra - Citizen Space, (May). Retrieved from:

www.nationalarchives.gov.uk/doc/open-government-licence/version/3/%0Awww.gov.uk/government/publications%0Awww.gov.uk/defra%0Ahttps://consult.defra.gov.uk/airquality/air-quality-plan-for-tackling-nitrogen-dioxide/

Guerreiro, C., de Leeuw, F., Foltescu, V., Schilling, J., van Aardenne, J., Lükewille, A., & Adams, M. (2012). Air quality in Europe - 2012 report, EEA Report No 4/2012. https://doi.org/10.2800/55823

Mead, M. I., Popoola, O. a M., Stewart, G. B., Landshoff, P., Calleja, M., Hayes, M., …, Jones, R. L. (2013). The use of electrochemical sensors for monitoring urban air quality in low-cost, high-density networks. Atmospheric Environment, 70, 186–203. https://doi.org/10.1016/j.atmosenv.2012.11.060

Mijling, B., Jiang, Q., de Jonge, D., & Bocconi, S. (2017). Practical field calibration of electrochemical NO₂ sensors for urban air quality applications. Atmospheric Measurement Techniques Discussions, (2), 1–25. https://doi.org/10.5194/amt-2017-43

Inhalation of pollutants by cyclists

It is evident that bicycles are increasingly more integrated into our cities as an alternative means of transport to motor vehicles, which contributes towards reducing emissions of atmospheric pollution, reducing traffic congestion and improving the user's physical condition. More and more cities are therefore involved in the development of infrastructures that favour this type of transport. However, this effort to promote the use of bicycles has not yet focused on mitigating the cyclists' exposure to air pollutants generated by traffic. This issue remains completely unattended despite the fact that numerous scientific studies have shown that the exposure of cyclists to traffic-related air pollutants causes significant adverse effects on their health, including respiratory problems (exacerbation of asthma), cardiovascular diseases and increased mortality (Janssen et al. al., 2011; Strak et al., 2011; Hoek et al., 2013).

A specific study was carried out in the LIFE+RESPIRA project, with a small number of volunteers (40) to quantify the dose of inhaled contamination in accordance with the physical intensity associated with the use of bicycles. The main objective was to estimate the risk of taking certain routes considering both the level of pollution and exertion. The information obtained is expected to be tremendously useful for urban managers, which facilitates decision making to improve the quality of life for cyclists and pedestrians

How physical activity effects the inhalation of air pollutants

When measuring the effects of pollution on pedestrians or cyclists exposed to the urban environment, two a priori different factors must be taken into account. On the one hand, there is the existing concentration of pollutants in the roads where they move around, which in turn depends on the density, distribution and nature of the sources of air pollution (motor vehicles, heating etc.), weather conditions, road layout, the time of year, the time of day, etc. The second factor is related to the activity that cyclists and pedestrians are carrying out when they are exposed to urban pollution. We speak of "activity" in the sense of physical exertion, since all of the air pollutants enter the body through the respiratory track and the air flow that we maintain with our environment is (among other things) related to the level of physical activity that is being carried out (Int Panis et al., 2010).

This is especially relevant in the case of cyclists because they experience higher respiratory rates than pedestrians, even when cycling at low speeds. This means that cycling on polluted roads is not recommended, but even less so if it involves high physical exertion (for example, going up a hill), since this greatly increases the respiratory demand. The greater the volume of air breathed, the more air pollutants are inhaled.

"Healthy" routes

In a city, there are multiple routes one can take to reach the same destination (Fig. 1). The shortest or fastest routes are usually the ones that are prioritised by navigation software. If they also took into account the estimated levels of pollution in the different streets of the city and the level of physical exertion carried out by cyclists when riding through the streets, the user would be able to choose a route to their destination that predicts a lower level of air pollution (MacNaughton et al. al., 2014).

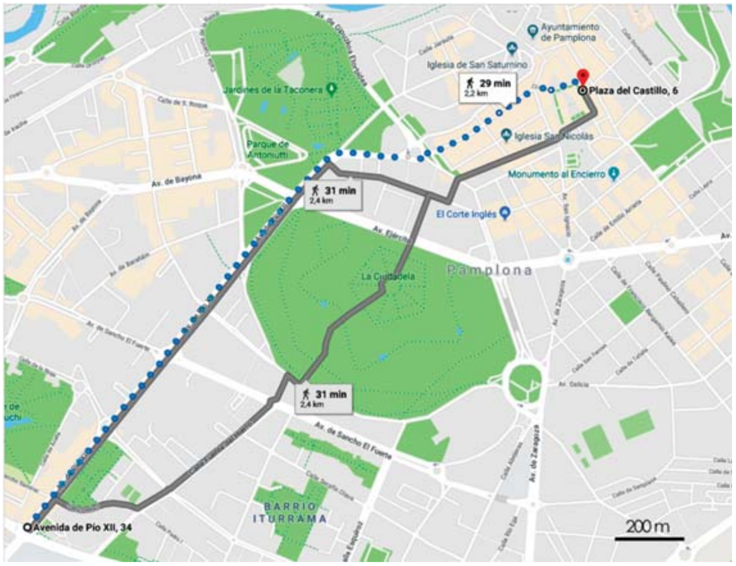


Figure 1. Possible alternatives for reaching the same destination.

Faced with a choice of three routes with the same travel time, which one would you take? The objective of the Healthy Route Planner is to add additional information related to pollution and physical exertion to calculate the best route to take. Image source: Google Maps.

The LIFE+RESPIRA project designed an App with this in mind, called the "planificador de rutas saludables" (Healthy Route Planner). It is a software tool, available both for the Web and for mobile devices, which allows users to choose the best route to take from one point to another, with the lowest amount of exposure to air pollution as possible.

To carry out this objective, not only the level of pollution but also the physical effort carried out by the cyclist travelling a certain route were taken into account. Since it is difficult to do a real-time measurement of the cyclists' respiratory rate during their activity, it was decided that heart rates would be recorded instead, and this would work as an indirect measurement of the respiratory effort. This parameter can be determined with sufficient precision and accuracy using a wide range of commercial devices. Thus, 40 volunteers would record their heart rates using commercial heart rate monitors (a wrist-watch with a chest belt sensor) during their trips through the city while recording the pollution levels with the Life+Respira devices.

The volunteers participated in a training course to learn how to properly use the heart rate monitors and access the generated data (Fig. 2).

They also underwent a spirometry test at the Navarre University Clinic (CUN), which allowed us to obtain a series of parameters related to respiratory air flow volumes. These values were subsequently used to estimate the volume of respiratory intake of air during their trips by bicycle and the amount of pollutants they were therefore exposed to in the routes that they took.

The spirometry tests conducted show the typical relationship between respiratory volume expressed as Tidal Volume (the volume of air that is displaced when we breathe in a normal cycle of inhalation and exhalation), age and gender (Fig. 3). Tidal Volume in women is lower than in men, and this respiratory parameter is reduced with age in both genders.

Figure 2. The documentation prepared to train volunteers on the use of the heart-rate monitors and the data download. .

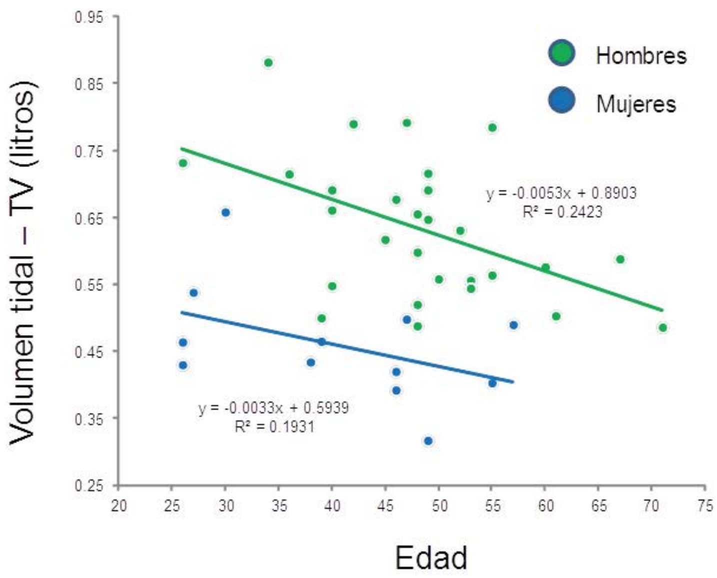


Figure 3. Relationship between respiratory Tidal Volume and volunteer's age.

What does the data tell us?

The position of each heart rate (HR) record was superposed on a Digital Elevation Model with a resolution of 5m (National Geographic Institute) to obtain the altitude of each point and, using spatial analyses, to calculate the speed values, road slopes and distance travelled by each volunteer (Fig. 4).

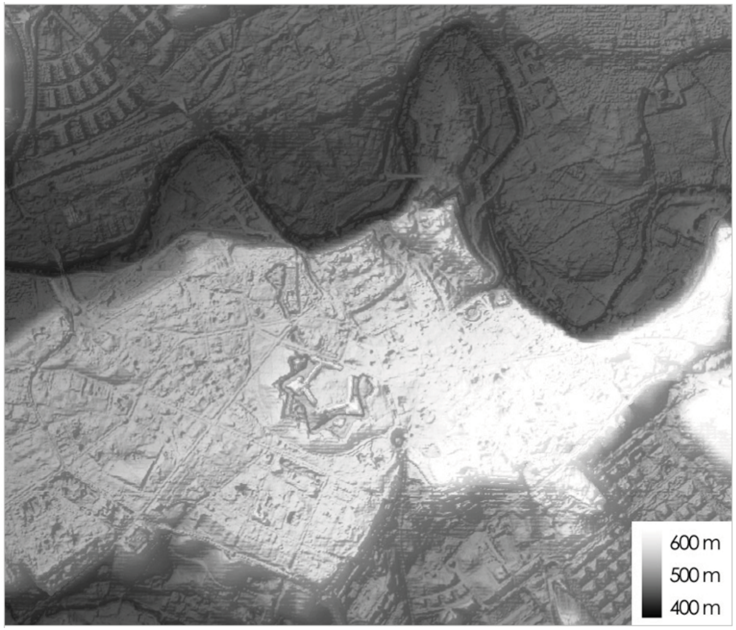


Figure 4. Horizontal Digital Elevation Model at 5-meter resolution (DEM05) of part of the study area. The DEM05 was obtained by interpolation of data information from the LIDAR flights from PNOA. Source: National Geographic Institute.

Before proceeding to analyse the data, the routes were divided into 30-second segments (the heart-rate monitors provided a HR reading every second), in which the statistics Average, Maximum, and Minimum were calculated for the variable speed, slope and HR.

In order to consider a segment valid, a series of conditions were introduced, which allowed for the assumption that the segment maintained certain uniform conditions of slope and orientation and in in which the volunteer was carrying out a stable physical effort.

These limitations for permissible data meant that a considerable amount of available information was lost, but in exchange, the statistical noise in the analyses was greatly reduced, thus providing higher quality information. The analyses were finally performed on more than 20,000 segments, each of which corresponded to sets of a maximum of 30 points (Fig. 5).

Figure 5. An example of one of the volunteer's trips with a heart rate monitor. The blue dots indicate places with heart rate information. The green lines are the segments that meet the requirements of uniformity in speed, and established gradients and orientation..

Several conclusions can be drawn from the statistical analyses so far, which corroborate the approach that led to the development of this action within the LIFE+RESPIRA project. On the one hand, cycling requires a great effort, as supported by the value of the average heart rate of all the volunteers, which reached 113 beats per minute. This mean varies significantly when studying each person individually, which points to both the heterogeneity in the representation of the group of volunteers, such as age, gender and also most likely to their different habits in regards to the use of the bicycle, such as the average speed of travel (global average being 4.3 metres per second, about 15 km/h) or the type of urban routes (Fig. 6).

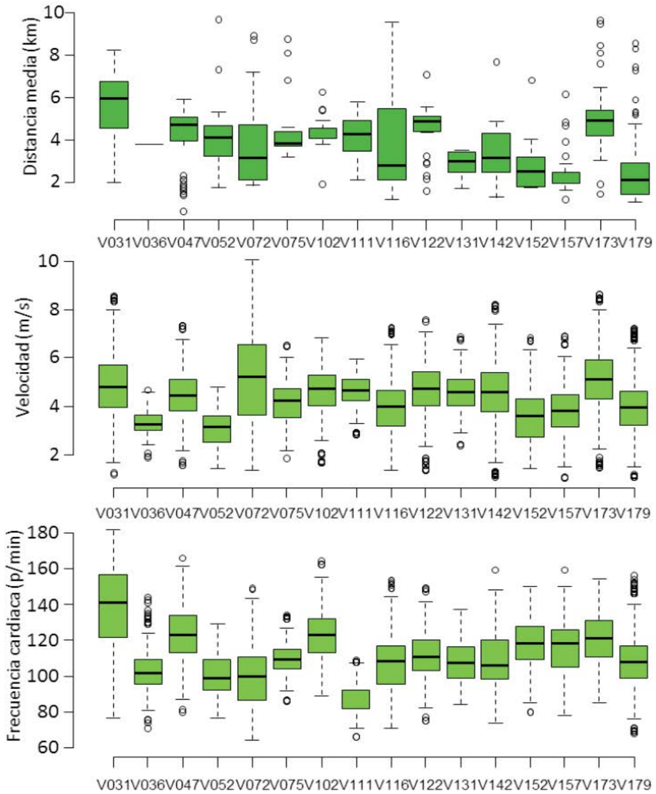


Figure 6. Route distances, speeds and heart rates recorded in some volunteers of the study. The green boxes indicate the most common values, while the lines and circles mark particularly extraordinary high or low values. The black line inside the box is the median value for each volunteer.

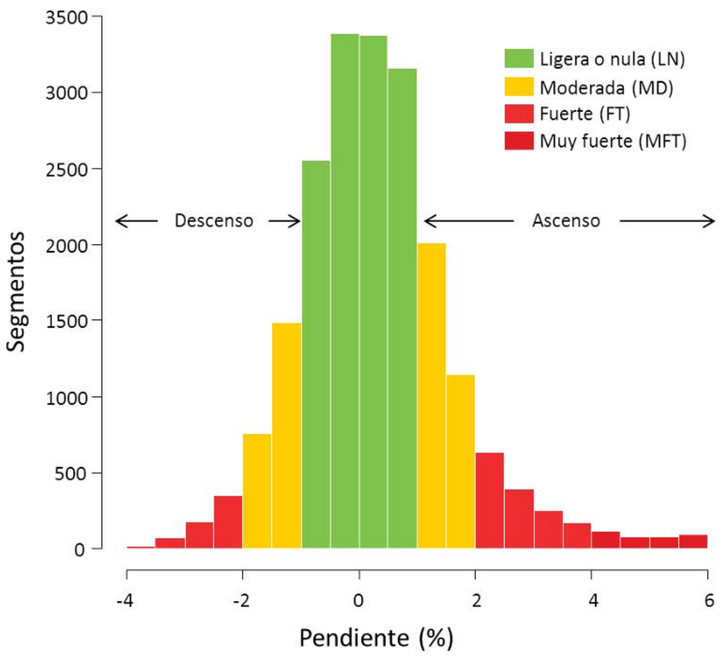


Figure 7. A histogram of the average slopes of the analysed segments. Most of the segments covered by the volunteers are in the green zone, considered to be segments of small or null slope, but average gradients of close to 6% in ascents and up to 4% in descents were recorded.

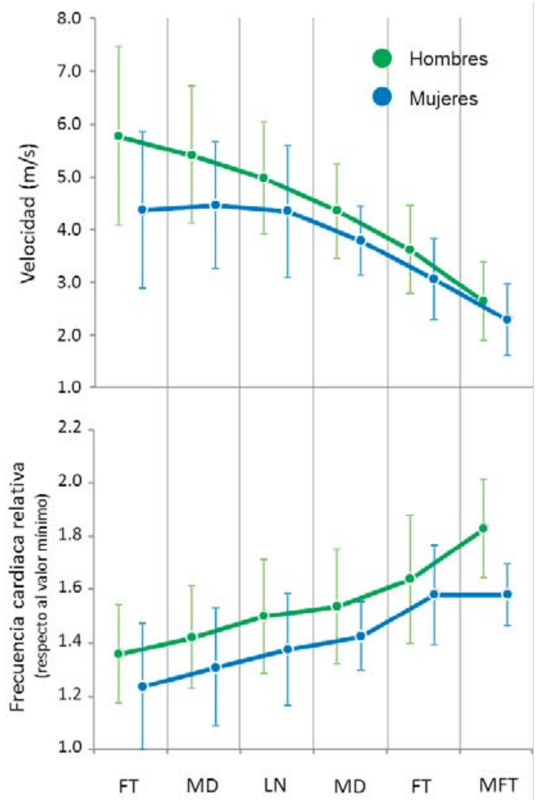
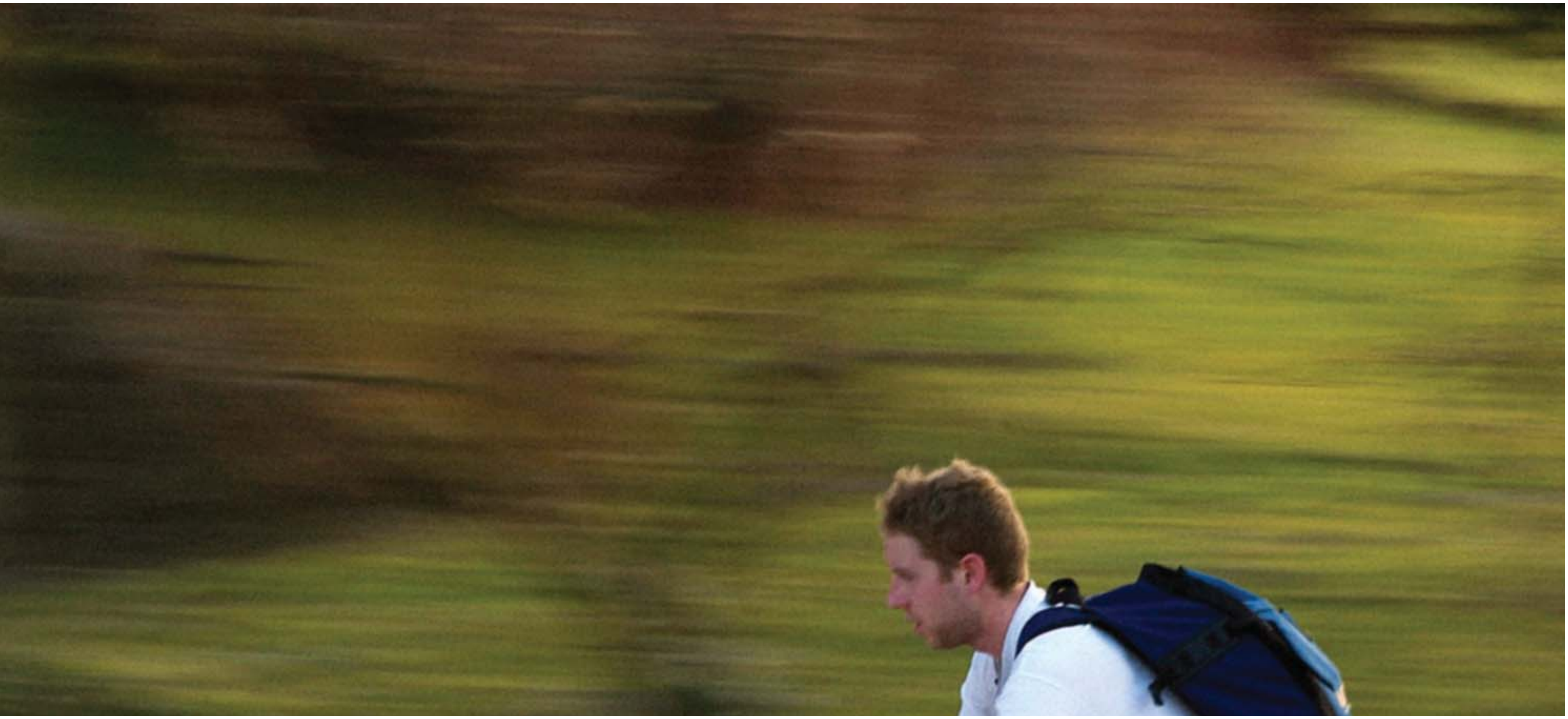


Figure 8. The relations between speed, heart rate and slope of the transect for men and women. The abbreviations of the slopes coincide with what is described in Figure 7 and are arranged in the same way (on the left, strong slopes in a downward direction and on the right, strong uphill slopes). The points represent the average values and the bars represent the standard deviations.

The majority of the trips occur in the areas with no or small slopes (<1%), as corresponds to the relief in the urban area where the routes were primarily located. However, segments with moderate (1-2%) or strong (2-6%) slopes were often identified. Both positive and negative slopes (Fig. 7) have a significant effect on the on two fundamental parameters with respect to pollution: the level of physical effort of the cyclist and the amount of time spent on a certain route.

The average speed in the segments of small or null slopes was slightly above 4m/s, while in the sections of higher slopes the speed reduced to 2m/s in the case of the ascents, or reaching 6m/s in descents (this effect is more evident in male cyclists). These notable differences in speed, determine the time it takes for the cyclist to travel a certain segment, which is significant from a pollution point of view, since steep roads are usually associated with a higher fuel consumption by motor vehicles and, therefore a greater production of polluting gases. The slope is also reflected in the cyclists' HR: the average values can fluctuate between 40%-80% with respect to the basal value, as the volunteers move to roads with steep or very steep ascending slopes (Fig. 8).



3. THE ROLE URBAN VEGETATION PLAYS ON THE QUALITY OF AIR

The effects of urban and peri-urban vegetation on air quality

Air pollution continues to be one of the main environmental challenges for our society, particularly in cities, where up to three quarters of the European population is concentrated. Although European policies to control air pollutant emissions have managed to significantly reduce emissions in recent decades, air pollution is still responsible for more than 400,000 premature deaths each year in Europe (EEA, 2015). For this reason, cities need to develop management plans and strategies to reduce the exposure of the population to air pollution, in order to minimize the effects and the enormous economic costs associated with them, as well as to improve the environmental quality and well-being of the citizens.

Urban and peri-urban vegetation has been recognized as a valuable tool for improving air quality in cities (Samson et al., 2017). Air pollutants can be removed from the atmosphere through wet-deposition washing processes, such as rain or snow, or by dry-deposition when air pollutants settle on surfaces. The relative importance of each of the processes depends in part on the weather conditions, with dry deposition being much more relevant in Southern than in Northern Europe. Urban vegetation provides an increase in surface area that is in contact with the air, which increases atmospheric dry deposition. Moreover, vegetation can absorb gaseous pollutants during the normal gas exchange that occurs through the stomata. This process efficiently absorbs the CO_2 required for photosynthesis. At the same time, other gaseous pollutants can also be absorbed by plants resulting in a reduction of their air concentrations.

Urban vegetation can also indirectly help to improve air quality through its effects on the microclimate. Through the shading of buildings and streets and evapotranspiration, the vegetation helps to lower indoor and outdoor temperatures, promoting energy savings associated with the use of air conditioning and thus encouraging the reduction of emissions. Moreover, lower environmental temperatures in turn reduce the photochemical processes in the atmosphere that generate secondary pollutants such as tropospheric ozone. In addition to the benefits related to air quality and climate, urban and peri-urban vegetation promotes the health and well-being of citizens by offering other environmental, social, cultural and economic services, collectively known as ecosystem services. These are the reasons that motivated the European Union to include urban vegetation within the Green Infrastructure Strategy whose main objective is to preserve biodiversity along with the services it provides.

Urban vegetation traits related to air quality

The capacity of urban vegetation to remove atmospheric pollutants depends on the morphological and physiological characteristics of each species. One of the most relevant traits is the amount of leaf surface that is in contact with the air and which is therefore capable of removing gases or polluting particles. The leaf surface can be expressed as the leaf area index (LAI), which indicates the amount of one-sided green leaf area per unit ground surface, or as leaf area density (LAD), calculated as the total one-sided leaf area per unit volume of the canopy. For this reason, trees with greater leaf area capture more atmospheric pollutants than other smaller vegetation, such as shrubs and meadows. Among tree species, conifers have a high leaf area index, which is why they are considered to be more effective at removing atmospheric pollutants (Tiwary et al., 2016). This capacity is also greater because the needles are not shed during the winter, so they offer this service throughout the whole year. On the other hand, the deciduous species lose their leaves during the winter, drastically reducing their surface area during this period. In Mediterranean environments, the abundance of evergreen broadleaf species adapted to dry climates, such as Holm

oak, increases the list of species that can be used in urban and peri-urban areas to improve air quality. In addition to the leaf area, the shape and spatial structure of the crown determine the porosity of the canopy, affecting the dispersion and deposition of pollutants. A higher density can increase the capture of pollutants up to a certain extent, but a very high canopy density can restrict the pollutants transport to the inner most parts of the canopy, thus limiting its overall filtration abilities.

Other traits related to the leaf surface are also relevant for air pollution removal. With the same leaf area, those species with rough surfaces or leaves covered with hairs or trichomes, or with abundant wax layers, encourage particulate matter deposition and prevent resuspension (Sæbø et al., 2012). Also the occurrence of salts and ions increases leaf's surface wettability, favouring particulate matter deposition and water-soluble gases dissolution (Grote et al., 2016).

In the case of gaseous pollutants, the species with high rates of stomatal conductance will be the most effective for reducing air pollution. Gas exchange through stomata is a process closely regulated in order to maximize photosynthesis while minimizing water loss by transpiration. Therefore, the stomatal conductance is controlled by changes in the environment, such as relative humidity, availability of water and nutrients, light, and concentration of CO_2 in the atmosphere. Stomatal conductance is also regulated by internal factors, such as plant hormones, which vary depending on the age and the growth stage of the plant. Atmospheric pollution can in turn alter stomatal functioning causing effects on plant development and growth. Any factor that causes the stomatal closure will reduce pollutant absorption. Therefore, it is essential that the urban vegetation is properly managed to ensure its good health and vigour, in order to maximize the possible benefits of improving air quality.

Numerous studies have found that conifers are more efficient at capturing large amounts of particulate matter than deciduous broadleaved trees due to the higher leaf area index and the larger deposition velocity (Sæbø et al., 2012). Besides, these species keep their leaves throughout the year. However, conifers are more sensitive to air pollution and to the salts that are used in winter to prevent ice forming. A combination of deciduous and evergreen species is therefore needed in order to maximize the benefits of improving urban air quality, provided that conifers are not located right next to the emission points, such as road forefronts or near streets with heavy traffic.

It is important to note that there can also be disadvantageous aspects of having vegetation in the city, which can negatively affect air quality. Vegetation and associated fungi produce particulate matter of biological origin, such as pollen and spores. Certain species produce pollen with high allergenic character, which can be worsened when combined with atmospheric pollution, representing one of the main problems associated with urban vegetation (Cariñanos et al., 2016). The allergenicity of the pollen depends on the species, so this criterion should be taken into account when choosing which species to plant in urban environments. Moreover, vegetation emits biogenic volatile organic compounds (BVOCs) which can contribute to the secondary formation of ozone and particulate matter through reactions in the atmosphere. Plants emit various types of BVOCs with different chemical characteristics, and so some produce more atmospheric pollutants than others. The BVOCs emission pattern depends not only on the species, but also on the environmental conditions and the state of health of the vegetation.

All these traits indicate that urban and peri-urban vegetation affects urban air quality, so this effect should be included as one of the criteria for urban tree species selection. It is important to note that proper management of vegetation that ensures a good state of conservation and vigour of the plants will facilitate the filtering capacity and the positive effects on air quality. Once the most suitable species have been selected (in terms of the specific traits of growth, structure and physiology), it is equally worth considering the distribution and placement of the trees, as will be explained in the following sections.

Characteristics of the urban tree vegetation of Pamplona

The LIFE+RESPIRA project evaluated the characteristics related to air quality of the urban trees in the city of Pamplona (Figure 1). The city has more than 87,000 trees of more than 300 species, which represents a significant diversity of urban trees. However, the 10 most abundant species represent 62% of the wooded area (Table 1), and more than a third of the species are only represented by less than 10 trees in the entire city. Interestingly, only 9% of Pamplona's trees are evergreen, which indicates that a very small percentage of urban trees can provide air quality-improvement services

Figure 1 Measurement campaign of stomatal conductance in urban vegetation during the LIFE+RESPIRA project.

during the winter, the time of the year when air pollutant concentrations tend to be higher.

Table 1 shows the available information on the traits related to air quality of the most abundant species present in Pamplona. Most of the 10 most abundant species have a medium capacity to mitigate air pollution, both gaseous pollutants and particulate matter. But it should be noted that 6 of the 10 most abundant species produce pollen with a high allergenicity index. In addition, 9 of them present medium or high emission rates of BVOCs. These results indicate that air quality in Pamplona could be improved by incorporating a larger surface area of evergreen species and tree species that maximize air pollution uptake.

Species	**Surface (%)**	**PFP**	**Air pollution mitigation**	**Stomatal conductance**	**Allergenicity**	**BVOCs emission**
Platanus x hispanica	16.9	2.3	Medio	65	Alto	Alto
Populus nigra	11.6	-2		110	Alto	Alto
Populus x euramericana	9.4	-2			Bajo	Alto
Aesculus hippocastanum	4.6	2.7	Medio		Medio	Medio
Populus alba	4.2	-2	Alto	289	Alto	Alto
Celtis australis	3.5			159	Medio	Medio
Ulmus minor	3.3			94	Alto	Medio
Acer negundo	3.2	1.7	Medio	76	Alto	Medio
Acer pseudoplatanus	2.9	1.7	Medio		Medio	Medio
Fraxinus excelsior	2.3	2.1	Medio	97	Alto	Bajo

Table 1. Characteristics of the 10 most abundant tree species in Pamplona related to air quality: percentage of the total woodland area of Pamplona corresponding to a species; PFP is the "pollution flux potential" index proposed by Tiwary et al. (2016), which represents the capability of the interaction with the atmosphere, providing the net effect between atmospheric pollutants released and/or deposited, higher values indicate more benefits for air quality; the ability to mitigate air pollution includes particulate matter and gaseous compounds according to Samson et al. (2017); stomatal conductance (mmol m^{-2} s^{-1}) measured under optimal physiological conditions during the Life+RESPIRA project, indicating the potential capacity of absorbing gaseous atmospheric pollutants; allergenicity index according to Cariñanos et al. (2016); emissions of BVOCs according to Samson et al. (2017).

The role of urban and peri-urban vegetation on air quality in areas without emission sources

In addition to the morphological and physiological features of the selected species, the location and configuration of the urban vegetation is an equally important factor in determining the ability to improve air quality. In those areas where there are no on-site atmospheric pollutant emissions, such as in peri-urban forests and gardens and parks, vegetation plays a fundamental part in filtering and reducing atmospheric pollutants. The use of air quality models has allowed the quantification of the contribution of peri-urban forests to the improvement of air quality, through facilitating deposition and therefore reducing concentrations of pollutants such as ozone or particulate matter in nearby areas. For example, it has been estimated that the disappearance of Mount El Pardo, (a forest located north of the city of Madrid), would cause an increase of up to 15% in ozone concentrations in the surrounding areas (Alonso et al., 2011). Most studies that analyse the role urban and peri-urban vegetation play in the city's air quality have been carried out with different types of models. In addition to the aforementioned air quality models, the most widely used model is the Urban Forest Effects model (UFORE, currently included in i-Tree), developed by Novak et al. (2008). This model combines information from a city tree inventory with monitored data of air pollutants and meteorological variables to estimate different environmental services such as mitigation of air pollution, CO_2 absorption or emissions of BVOCs at city scale. All these models have some key constraints and recently more emphasis has been placed on the need to carry out experimental measures to validate, reparametrize, and improve model estimates.

The LIFE+RESPIRA project has made a significant contribution in this regard, demonstrating experimentally that, in areas without emission sources, the concentrations of different atmospheric pollutants such as ozone, nitrogen oxides, ammonia and nitric acid are significantly lower below tree canopies than in open areas without trees (Fig 2, García-Gómez at al., 2016). These results confirm the predictions made with different models and highlight the importance of the presence of trees in sensitive areas, such as playgrounds, school playgrounds, sports areas, hospital gardens or homes for the elderly, etc., in order to reduce the exposure of the population to air pollution, especially the most vulnerable (children, the elderly and people with a history of illnesses or chronic patients).

The effectiveness of vegetation barriers at reducing exposure to atmospheric pollution

Urban vegetation can also be effective at stopping the dispersion of pollutants to areas that should be protected, for example to separate the bike lanes from the road, or to protect sensitive common areas intended for the population, such children's playgrounds, parks, sports and leisure areas etc. that are close to roads with heavy traffic. LIFE+RESPIRA has demonstrated through experimental measurement campaigns (Fig. 3) that the distance between the bike lanes and the traffic lanes on the road is the main factor to decrease the concentra-

Figure 3. Experimental measurement campaign to sample the effect of hedges on air quality in Pamplona: LIFE+RESPIRA project.

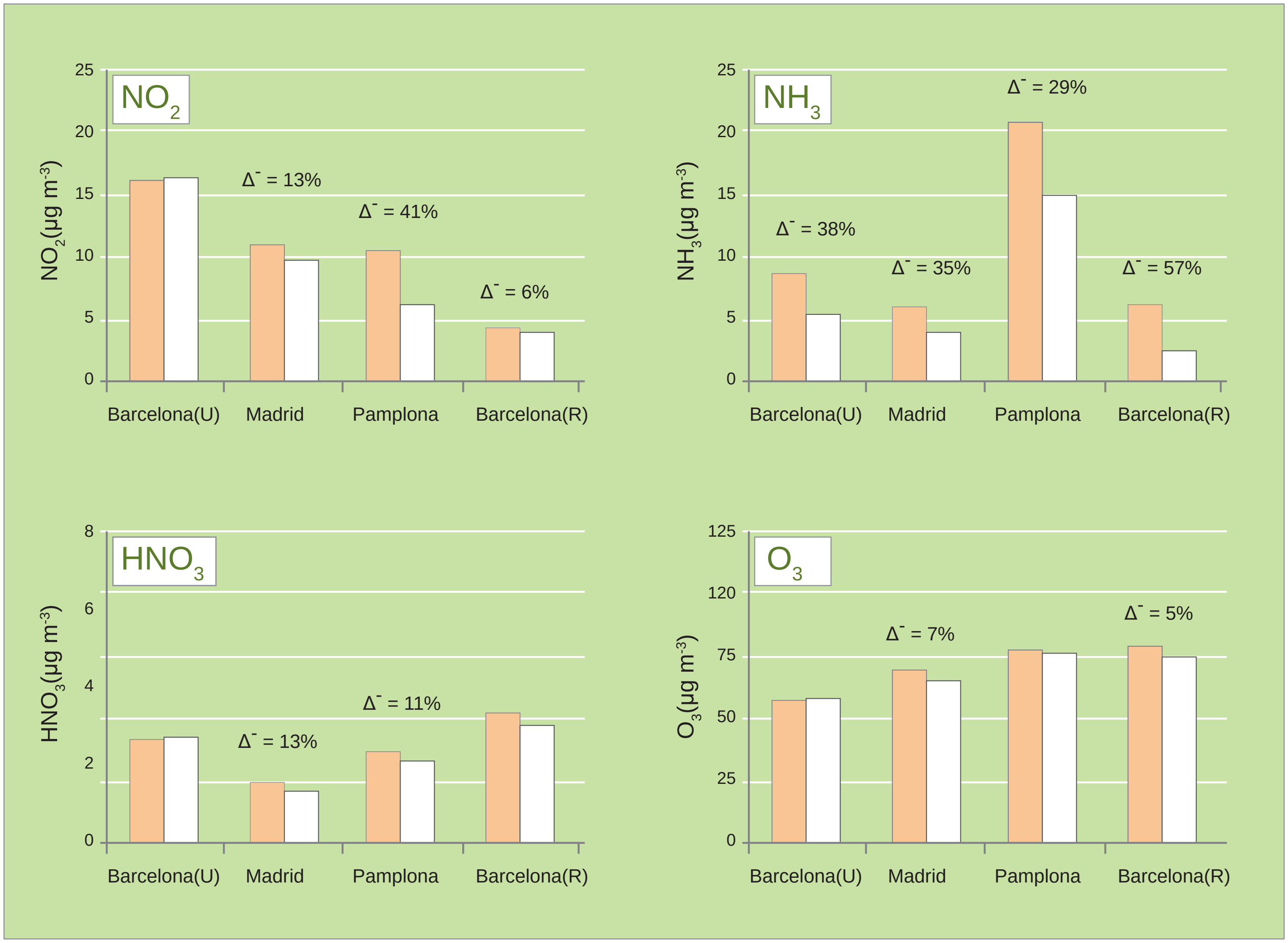


Figure 2. Concentrations of air pollutants in open, woodless areas (orange bars) and under the tree canopy in peri-urban forests (green bars). The values represent the mean value from two years of measurements. The decrease in concentration (Δ-) is only shown for cases that are statistically significant. Data published in García-Gómez at al. (2016).

tions of black carbon in the air (which is one of the main pollutants linked to traffic). When it is not viable for a cyclist to move away from the road, the use of separation vegetation barriers, (in particular hedgerows) helps to reduce the exposure to polluting particles emitted by traffic by up to 30% (Fig. 4). The efficiency of the vegetation barrier will depend not only on the dimensions, density and the selected species, but also on the prevailing winds that carry pollutants emitted by traffic, increasing efficiency in those conditions in which prevailing winds carry pollutants from the road towards the hedge (Fig. 5).

Roadside tree barriers can also be effective, but with this type of vegetation it is important to take into account the height at which the emissions occur and the exposure to the population, and the height of the tree canopy. If the crown becomes leafy at a certain height (typically 3-4 metres) to facilitate the transit of vehicles or people underneath, this kind of vegetation barrier will be less effective at reducing air pollution at a pedestrian or cyclist height compared to shrub or hedgerow barriers, which have full leaf coverage from the ground. The combination of experimental measures with pollutant dispersion models (see Chapter 4), has shown that vegetation barriers that are made up of hedges, with a tree line behind, are particularly efficient to reduce the exposure to pollution at a pedestrian or cyclist level. These results also indicate that it is necessary to take into account the aerodynamic effects of the barrier depending on the prevailing winds, the size and density of the vegetation, and its position from the road, in order to maximize the beneficial effects of vegetation barriers on air qualityefectos beneficiosos de las barreras vegetales.

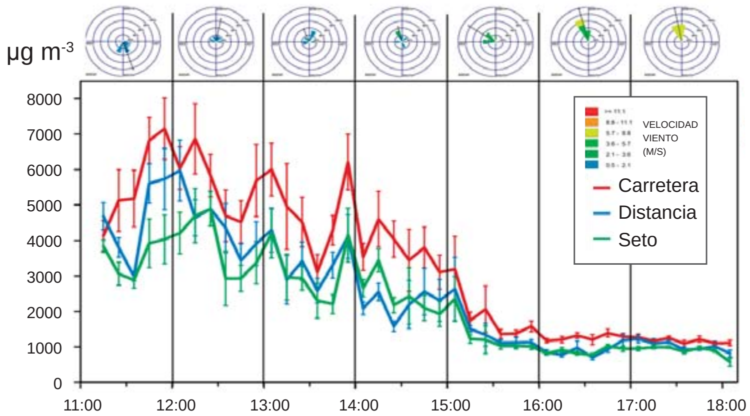
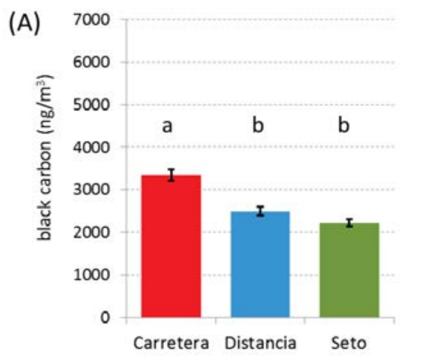


Figure 4. Analysis of the effectiveness of a hedge as a vegetation barrier at dispersing near-road air pollution. The figure shows the black carbon concentrations and the wind diagram on Avenida de Navarra (Pamplona) measured in the LIFE+RESPIRA project. The red line represents the concentrations measured at the roadside next to traffic; the green line shows the concentrations on the other side of the hedge; the blue line shows the concentrations using the same distance as the sensor behind the hedge, but without the vegetation barrier between them.



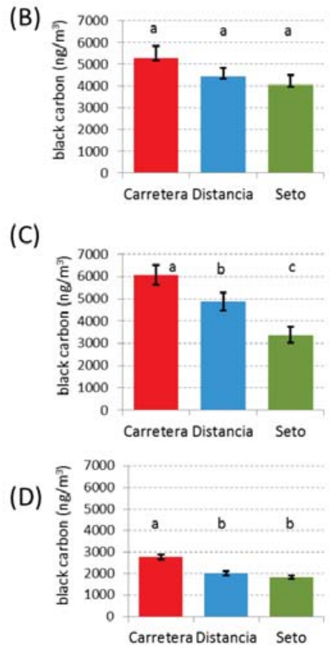


Figure 5. Analysis of the effectiveness of a hedge as a vegetation barrier for the dispersion of air pollution. The figures show the average black carbon concentrations throughout the campaign (A); the average values in calm wind conditions (B); the average values in windy conditions coming from the road (C); and the average values with wind blowing in a parallel direction to the road (D).

The effect of roadside trees on the air quality in street canyons

The role urban trees play on the air quality in narrow streets with relatively heavy traffic is more controversial, since vegetation can be an obstacle to the street ventilation, preventing the dispersion of emitted pollutants, with this effect being more significant than its capacity to capture pollutants. The CFD-type (Computational Fluid Dynamics, see chapter 4) atmospheric models, which simulate the concentration and distribution of pollutants at street level, have been used to estimate the effect of roadside trees. However, it has been acknowledged that the scarce experimental data have prevented wide model validations until now. Thanks to the collaboration and participation of the citizens, who allowed the installation of sensors on their buildings, the LIFE+RESPIRA project was able to perform several monitoring campaigns to measure meteorological parameters and the concentration of atmospheric pollutants at various heights on the facades of buildings within street canyon with and without roadside trees (Figure 6). When trees were not present, the concentrations of black carbon were found to be 19% lower at a height of 10 metres when compared with concentrations at 3 metres. On the other hand, the presence of trees reduced that difference to 10% on average (Fig. 7). These results confirm that the presence of urban trees reduces the vertical dispersion of the particles emitted by traffic, which may sometimes worsen the air quality in streets with trees and intense traffic. The effect of roadside trees on the distribution of temperature in this type of streets has also been verified, validating the predictions obtained with atmospheric CFD models. The modelling, combined with the experimental measures, detected that roadside trees can also act as a horizontal barrier for the entry of pollutants emitted in nearby streets with heavy traffic. For this reason, neighbourhoods with narrow street canyons require detailed studies on the distribution of the emissions, the prevailing weather conditions and the geometry of the streets in order to help to decide on the design, positions and size of the roadside vegetation in a way that maximize the benefits for climatic comfort while avoiding the interruption of street ventilation that could aggravate air quality problems.

Figure 6. Measurement of atmospheric pollutant concentration and meteorological parameters at different heights in a street canyon in Pamplona as part of the activities of the LIFE+RESPIRA project.

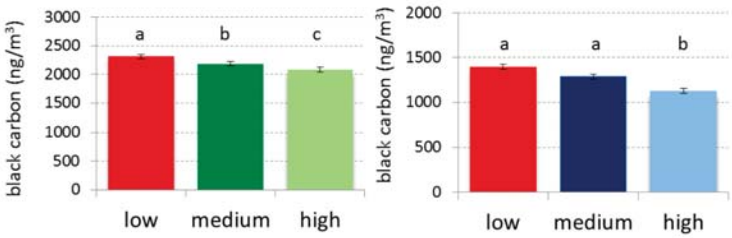


Figure 7. Concentrations of black carbon at different heights on the facades of a street with the presence of roadside trees (left) and in another similar street without trees (right) in Pamplona as part of the activities of the LIFE+RESPIRA project.

Conclusions

Urban vegetation is an important tool for the management of air quality, but its effectiveness depends on a series of factors that must be taken into account, starting by choosing the right species. Characteristics such as the canopy size, leaf longevity, foliar surface (rough or with hairs), or the high gas exchange rates are traits that can contribute to reduce air pollution. In order to avoid possible harmful effects on air quality, other species traits need to be considered such as pollen allergenic potential, or the emission of volatile organic compounds. The appropriate management of urban vegetation ensuring plant health and vigour will also maximize the filtration capacity and reduction of atmospheric pollution.

In addition to the criteria of species selection and the proper maintenance of vegetation, it is essential an adequate design and configuration of the green areas and vegetation barriers to help abate the exposure of the population to air pollution. Narrow streets with heavy traffic need detailed studies to design a suitable vegetation distribution that offers climatic comfort without worsening air quality through decreasing street ventilation. Finally, it is important to note that although urban and peri-urban vegetation can help to improve air quality, the only effective strategy would be to reduce the emissions inside the city, mainly those related to traffic, which are the main cause of air pollution problems in cities.

References

Alonso, R., Vivanco, MG., González-Fernández, I., Bermejo, V., Palomino, I., Garrido, JL., Elvira, S., Salvador, P., Artíñano, B. (2011) Modelling the influence of peri-urban trees in the air quality of Madrid region (Spain). Environmental Pollution 159: 2138–2147

Cariñanos P, Adinolfi C, Díaz de la Guardia C, et al. (2016). Characterization of allergen- emission sources in urban areas. Journal of Environmental Quality 45: 244-252.

European Environmental Agency (2015). SOER 2015 — The European environment — state and outlook 2015. A comprehensive assessment of the European environment's state, trends and prospects, in a global context. 212 pp.

García-Gómez H, Izquieta-Rojano S, Aguillaume L, González-Fernández I, Valiño F, Elustondo D, Santamaría JM, Àvila A, Fenn ME, Alonso R. (2016). Atmospheric deposition of inorganic nitrogen in Spanish forests of Quercus ilex measured with ion-exchange resins and conventional collectors. Environmental Pollution 216: 653-661.

Grote R, Samson R, Alonso R, Amorim JH, Cariñanos P, Churkina G, Fares S, Le Thiec D, Niinemets Ü, Mikkelsen T, Paoletti E, Tiwary A, Calfapietra C. (2016). Functional traits of urban trees: air pollution mitigation potential. Frontiers in Ecology and the Environment 14: 543-550.

Nowak DJ, Crane DE, Stevens JC, Hoehn RE, Walton JT, Bond J. (2008). A Ground-Based Method of Assessing Urban Forest Structure and Ecosystem Services. Arboriculture & Urban Forestry 34: 347-358.

Sæbø A, Popek R, Nawrot B, Hanslin HM, Gawronska H, Gawronski SW. (2012) Plant species differences in particulate matter accumulation on leaf surfaces. Sci Total Environ. 427-428: 347-354.

Samson R, Grote R, Calfapietra C, Cariñanos P, Fares S, Paoletti E, Tiwary A. (2017). Urban trees and their relation to air pollution. En: Pearlmutter D, Calfapietra C, Samson R, O'Brien L, Krajter S, Sanesi G, Alonso del Amo R (eds), The Urban Forest, Future City 7, Springer. Pp 111-144.

Tiwary A, Williams ID, Heidrich O, et al. (2016). Development of multi- functional streetscape green infrastructure using a performance index approach. Environmental Pollution 208: 209-220structure using a performance index approach. Environmental Pollution 208: 209-220.

4. HIGH RESOLUTION MODELS TO ASSESS AIR QUALITY

Modelling of air quality in Pamplona and measures to improve it

Modelling of air quality and evaluation of results

In the streets and squares of a city the air flows following quite complex patterns derived from the disturbance caused by the buildings and obstacles existing in the streets (trees, cars, etc.). These disturbances also provide an additional turbulence that affects the exchange of physical properties (moment or energy), including the dispersion of existing pollutants in the ambient air. These patterns of air circulation in streets and squares cannot be simulated using standard models at other major scales, such as the models used for forecasting the weather. For cities very high resolution models has to be used in order to clearly describe urban obstacles such as, buildings or street trees. These models are the well-known CFD (Computational Fluid Dynamics) atmospheric models, which allow the evolution and distribution of pollutants in the streets of a city to be simulated with high spatial detail (resolution of one meter).

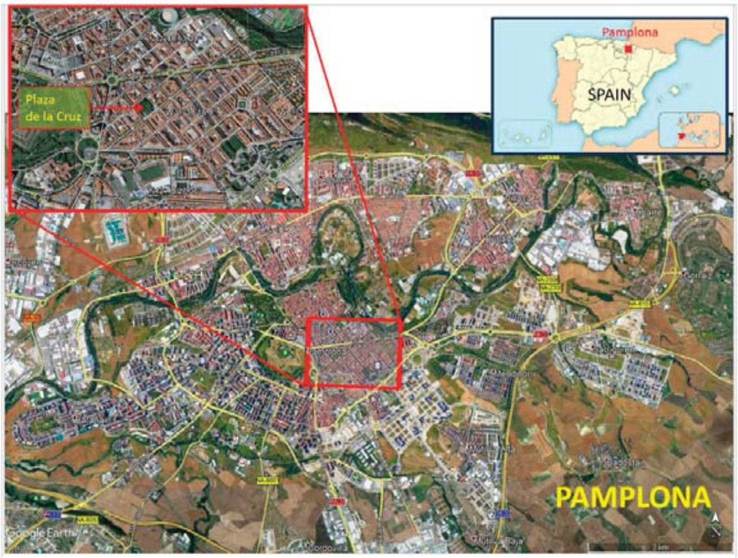


Figure 1. Map of Pamplona and the district of Plaza de la Cruz showing approximately the domains used to simulate pollution in the city with CFD models.

The CFD models (software used STAR-CCM + from Siemens) have been used in the LIFE + RESPIRA Project to simulate with very high resolution the streets of Pamplona in order to give very detailed information on how pollutants are distributed in streets, squares and city parks and the way they evolve over time. The methodology used is based on others works of the scientists of this project such as Parra et al. (2010), Santiago et al. (2013) and Santiago et al (2017a). The information resulting from these high-resolution simulations has been used in other project activities, such as the estimation of the population's exposure to pollution. The simulations of air circulations and dispersion of urban pollutants in Pamplona have been carried out using two different scales: 1) urban district scale and 2) city-wide scale. In the case of the urban district, an area of approximately 1 km^2 was chosen around the Plaza de la Cruz (Fig. 1).

However, the use of these models must be preceded by a work of fine tuning that includes their adjustment and validation. In the case of the urban district, in order to analyze the ability of the CFD model to reproduce the experimental observations, the measurements of the air quality station of Plaza de la Cruz and those of the intensive measurement campaigns carried out in this district were used. Experimental campaigns were carried out in two parallel streets very similar in terms of traffic, one with urban trees (Street San Fermín) and another without it (Street Tafalla). This comparison between the results obtained from the simulations (wind speeds and concentration of pollutants) and the experimental data measured, have demonstrated the ability of these CFD models to reliably reproduce what has been observed (Fig. 2). In this study, the great spatial variability of the concentration of pollutants within and along the streets has been revealed, with significant differences being

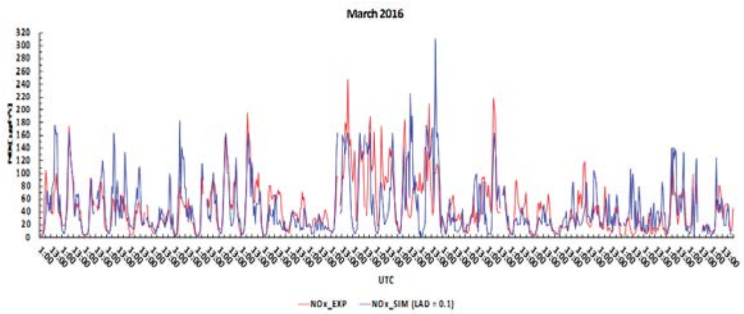


Figure 2. Evolution of hourly concentrations of NOx at the Plaza de la Cruz station estimated by the CFD model (blue) and measurements at the mentioned station (red) for March 2016.

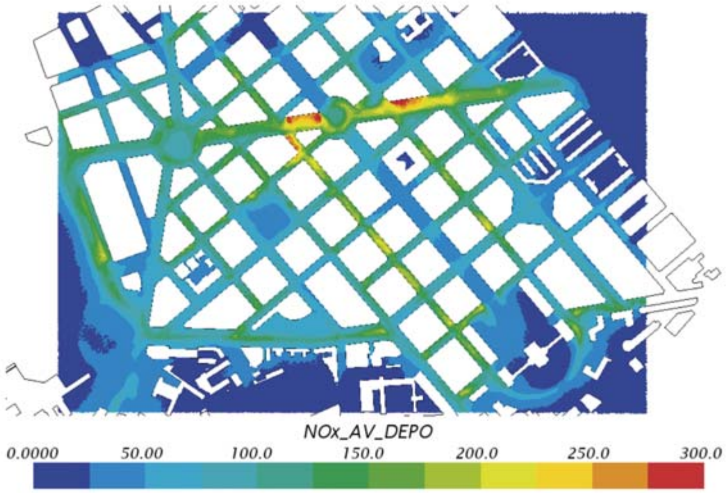


Figure 3. High resolution map of average NOx concentration (μg/m^3) during the period from 1st to 1^{4th} March 2015 estimated by the CFD model for the district of Plaza de la Cruz (Pamplona).

found, for example, between a sidewalk and the one opposite (Fig. 3). The atmospheric conditions, especially the direction and speed of the wind and the leaf density of the urban vegetation (trees in the streets) can alter the distribution of pollutants.

On the other hand, a very high resolution (5 m) CFD simulation of the dispersion of pollutants in a city such as Pamplona (approximately 42 km^2) was carried out for the first time in Spain. Although this fact has been an extraordinary computational effort, its results have allowed a broad and detailed view of how pollutants are distributed in the city and how they evolve throughout the day according to the season of year (Fig. 4). The simulations have focused on nitrogen oxides (NOx) as the most important pollutant in the city and mostly emitted by traffic. This has made it possible to identify the most contaminated streets and at the times of the day there are greater or lesser concentrations of pollutants (Rivas et al, 2017).

The results obtained by these simulations of the whole city have fitted well the observed concentrations of nitrogen oxides in the air quality stations (Fig. 5). They have also been compared with the huge number of data collected by micro sensors that volunteer cyclists of the project have carried out in their regular trips throughout the city (see chapter 2).

The simulations for all of Pamplona have been used to:

- Estimate the exposure of the population to pollution, allowing economic evaluation studies of its impact on the health of citizens.

- Provide input to an smartphone App dedicated to the navigator of healthy routes, which will allow cyclists and pedestrians to look for the least contaminated routes in their journeys through Pamplona, as well as essential information for the development of a Mobility Plan for the city.

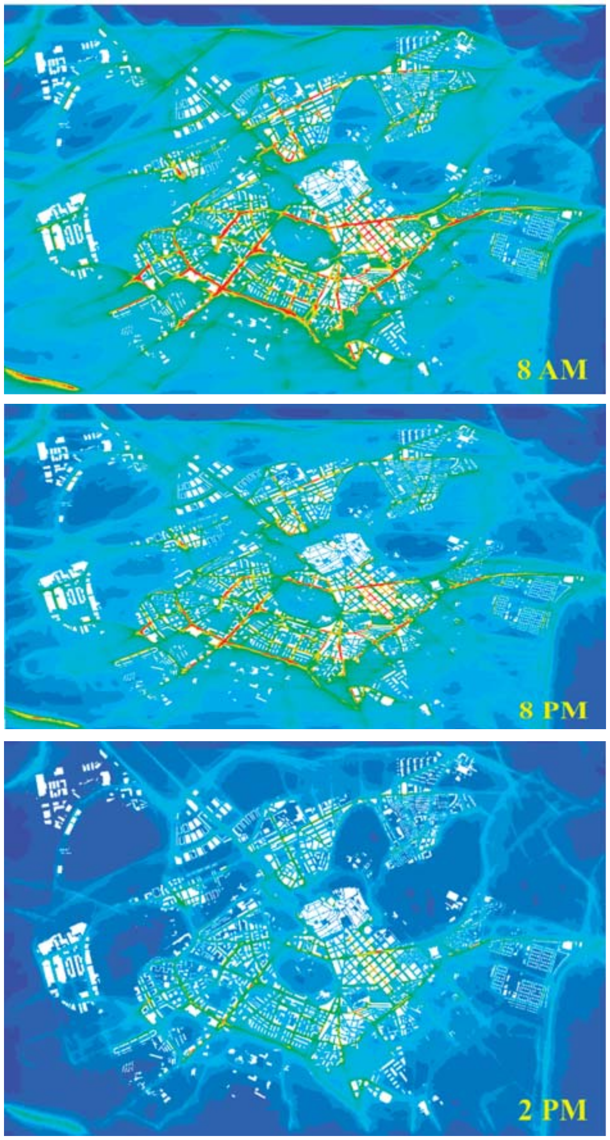


Figure 4. High resolution time maps of the average annual NOx concentration during 2016: 8 a.m., 2 p.m., 8 p.m., all of them local time.

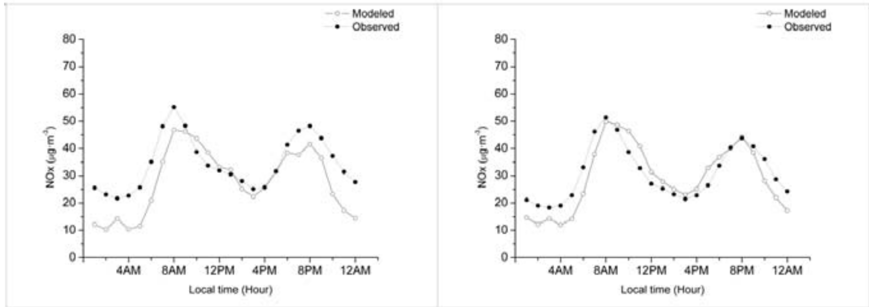


Figure 5. Comparison between modelled and observed hourly NOx concentrations. Average annual day in: a) Pamplona-Iturrama, b) Pamplona-Rotxapea.

In addition, this high-quality performance of the CFD models has allowed them to be used to investigate the possible effect of measures to mitigate or reduce air pollution in Pamplona.

Modelling the effects of urban vegetation on air quality

To investigate the impact of urban trees on air quality, simulations have been carried out analyzing how pollutants are dispersed according to the density of the canopy (during the winter it is less than during the summer). Keep in mind that vegetation has two opposite effects. On the one hand there is the elimination or deposit of pollutants: the vegetation is a sink for contaminants since it captures or absorbs them through its leaves. On the other hand, there is the disturbance that they produce to the air circulations, reducing the ventilation and the dispersion of pollutants. Therefore, it has been investigated which process is dominant in the streets of a city, analyzing the concentrations of pollutants resulting from different simulations carried out for the District of Plaza de la Cruz, assuming different densities of foliage (little foliage would represent winter conditions, a great deal of foliage would be summer conditions), and different intensities of the process of depositing pollutants by the vegetation (different deposit speeds, since it depends on the type of species, etc.).

It has been found that the effect of reducing the dispersive capacity and altering the air circulations dominates in most conditions over the sink effect. Figure 6 shows the relationship between the different rates of deposition of pollutants (more deposition velocity,

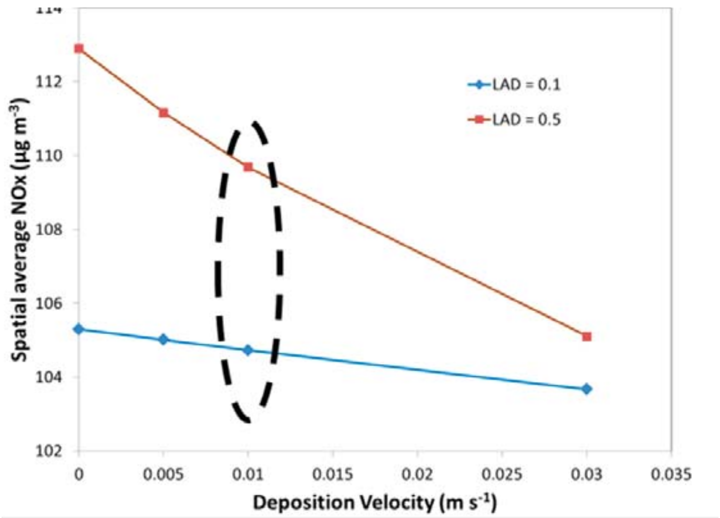


Figure 6. Variation of the mean spatial concentration of NOx at 3m above the ground as a function of the rates of pollutant deposition rates by vegetation for two foliage densities (LAD).

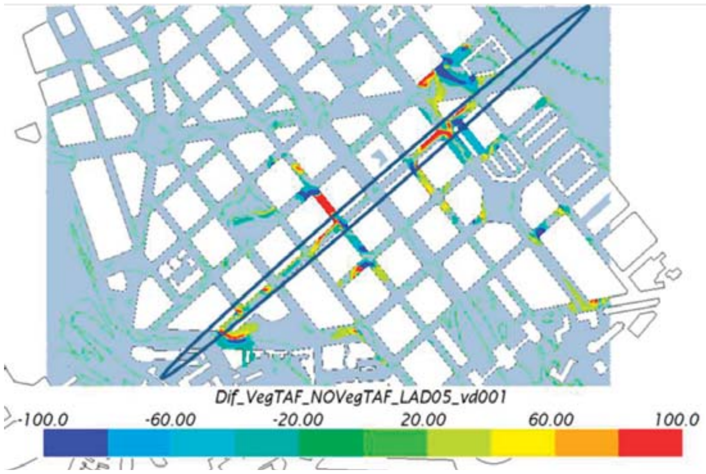
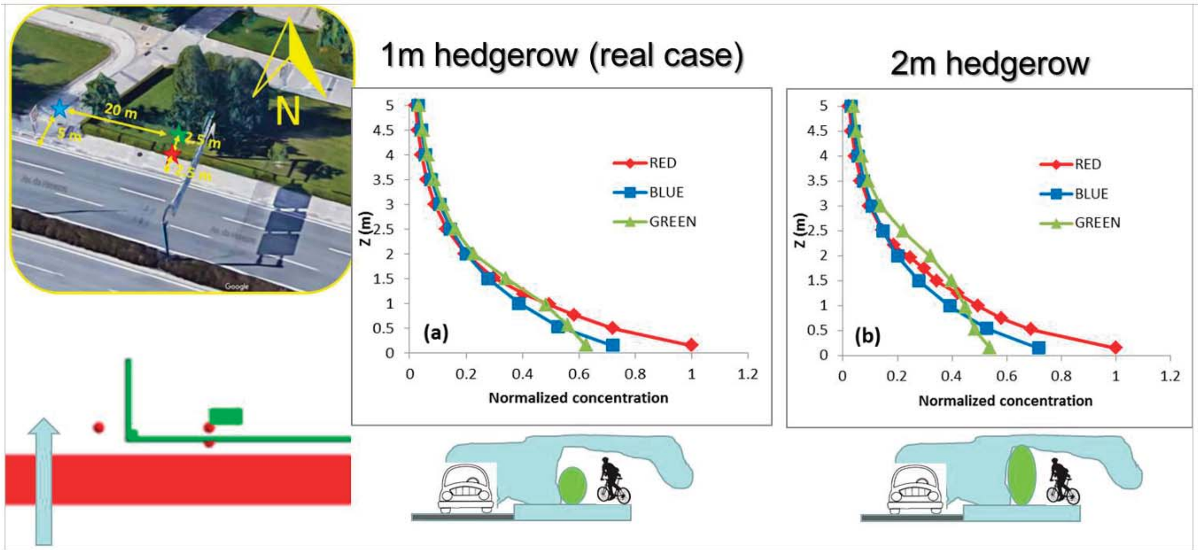


Figure 7. Differences of concentration when comparing a real case (without any trees in the street) with a virtual one (with trees in the street) Red indicates that the concentration increases in the virtual scenario and grey the area where the modelled differences are less than 20 $\mu g\ m^{-3}$. The continuous line points to Tafalla Street where virtual tree placement has been simulated.

more elimination or capture of pollutant by vegetation) with the spatial average of the concentration of NOx at 3 meters above the ground in the area of study for two cases of different density of foliage represented by the Leaf Area Density (LAD) (greater LAD, dense foliage). It can be seen that when the foliage is denser, the concentrations of NOx next to the ground are higher than when it is not very dense. In addition, although the process of deposition (capture) of pollutants by the vegetation is intensified (higher deposition rate), the concentration of contaminants will always be greater when the foliage is denser, although that the difference will be less and less compared to the case of the thin foliage. It must be considered that the area that was simulated is characterized by streets with traffic covered by large trees. In these cases, in which the treetops cover a large part of the street and the traffic is emitting pollutants, there is a tunnel effect that reduces the ventilation of the street, accumulating pollutants emitted by cars near to the ground. As a result, pedestrians and cyclists who travel on the road or sidewalks breathe more polluted air (Vranckx et al, 2015 and Santiago et al, 2017a and b).

Also, an interesting simulation exercise has been carried out with the CFD model consisting of seeing what happens if, in a street that does not have urban trees; large trees with different degrees of foliage density are placed on its sidewalks. This has been done for Tafalla Street, next to Plaza de la Cruz, which originally had no large trees on its footpaths. The results shown in figure 7 indicate that planting trees in a street with traffic has a significant impact not only in Tafalla Street itself, but in nearby streets altering the spatial distribution of pollutants. This indicates that any action of this type on a street must be accompanied by a previous study to see what effects on air quality can be expected, since each case and each street have their own particularities.

Figure 8. Results of the simulations of the experiments on the effect of hedges on air quality for the real case of hedge 1 m high and another hypothetical 2 m high. The colours of the curves correspond to the measurement points in the field campaigns, as shown in the upper left image.



The results shown so far, together with those of the chapter on urban vegetation, indicate that vegetation can exert a potent barrier effect against pollution. If we manage to separate pedestrians or cyclists from traffic through plant barriers, we will surely reduce the concentration of pollutants in the air they breathe. This has led us to investigate how this effect can be. For this, we have used data the measurement campaigns that have been carried out within this project to study the effect of hedges and trees located on the footpaths of large avenues with traffic (see chapter 3), and simulations have been carried out with the model CFD trying to replicate the actual conditions of the measurement campaigns, and later additional ones to see what would happen in other conditions, for example, with higher hedges.

The simulations carried out of the real case studied in the measurement campaign, which corresponds to a low hedge of 1 meter high located on the edge of a park with the sidewalk of an avenue of Pamplona (without buildings) with the wind blowing perpendicular from the road. This shows that the concentration of pollutants behind the hedge at ground level is reduced by more than 35% compared to the measurement in front of the hedge, and 15% compared to a point without hedge located at the same distance from the road. However, at the level of the height of the hedge (1 m) the estimated concentration exceeds that which would be at the point without hedge, equaling that which would be just in front of the hedge at the same height (Fig. 8).

Another simulation has also been carried out assuming a hedge of 2 m in height. The result shows a greater decrease in concentration behind the hedge next to the ground. As before also it is observed that, when we approach heights above half the height of the hedge, the concentration again exceeds what there would be if not. As before, it is observed that the concentration around the upper half of the hedge again exceeds the one which would be without the hedge.

It is evident that the aerodynamic effects make the air that go through the hedge more concentrated in pollutants per m^3, whilst the lower part behind the hedge remain pollutant-free, because of the wake effect. Considering the height of a person, we should consider implanting higher hedges or combined with trees that suppose a higher barrier and that make the height of protection (less pollution than without hedge) is higher. We must also consider what would happen in other configurations, for example, if we consider trees located behind the hedge or the effect of a building, that is, a typical configuration of driveway-hedge-sidewalk-building. This shows that here there is still a fairly open field of research in order to determine which urban vegetation configurations are most suitable to ensure good protection (separation) of the pedestrian areas or bike lanes from the roadways.

Measures to improve air quality

If we want to reduce air pollution in a city, it is obvious that reducing or restricting vehicle traffic has to be considered as a measure at least in those areas of the city with the worst air quality (Parra et al, 2010). Based on this idea, a set of simulations focused on the district of Plaza de la Cruz have been carried out assuming different scenarios of reduction or total restriction of traffic applied to the secondary streets of that district. It has been considered that these measures are applied to a different number of streets, that is, the reductions or restrictions of traffic in a set of smaller streets (just those closest to Plaza de la Cruz) and another area much wider that encompasses this mentioned area (extending to the East). It has been considered the reduction of 100% (total traffic restriction), 80% (partial restriction) and also the redistribution or diversion of restricted traffic in the affected streets towards the main avenues that surround those areas (0% without redistribution, 30% and 60% redistribution).

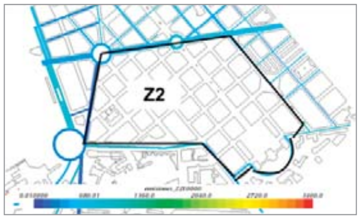
The volume of results is quite large, since it is a total of 12 simulated scenarios, but the general conclusions are the same for the large area of restrictions as well as the small area. It can be affirmed that a total traffic restriction has made a big impact on the air quality of the affected area. Pollution in the Plaza de la Cruz would have decrease by more than 70% on average (i.e., it would almost disappear) if there was no redistribution or diversion of traffic to the large avenues surrounding the area (Fig. 9). But this case is not very representative, since it is very likely that the restriction of the traffic implies that air takes different paths through the avenues.

Assuming that 60% of the traffic in small streets is diverted to the avenues, the reduction of pollution in Plaza de la Cruz is 50% on average, which is also a very important reduction. However, the increase in pollution in the surrounding large avenues and nearby streets is very significant (above 80% in many sections). On the other hand, the total restriction of traffic in these areas considered is very unrealistic, since it is necessary to allow certain traffic of private vehicles of residents, commercial distribution, and/or public services: transport (for example, taxi), cleaning and rubbish collection, emergencies, etc.

Based on this idea, we have contemplated scenarios in which traffic is reduced by 80%, leaving 20% of unrestricted traffic in the studied areas. In the case of that there is no increase in traffic in the surrounding avenues, pollution in Plaza de la Cruz decreased by 50% on average, but when a traffic increase of 60% is assumed in the avenues, the concentration in Plaza de la Cruz drops less than 40%, and increases in the avenues and surrounding streets by more than 80% in several zones (Fig. 9). This shows that traffic restrictions are very effective measures in the areas where they are applied, but may have an increase in pollution in the surrounding streets and avenues if complementary measures are not adopted (public transport enhancement, for example) that avoid or counteract the possible increase in traffic in avenues and surrounding streets (diverted to avoid the restriction zone).

Furthermore, in the last few years new technologies and different materials have been developed and seem to clean or reduce the pollution in cities. One of those materials is the group called photocatalytics, based on titanium oxides and characterized by its ability to react with nitrogen oxides under the effect of solar radiation (Lim et al., 2000 and Dalton et al., 2002). In other studies in which CIEMAT has participated (LIFE MINOx Street project), consisting of field experiments in real streets and modelling exercises, it has been seen that the efficiency of such materials (used in the form of tiles, paints, pavements) to eliminate nitrogen oxides in a real urban atmosphere is quite low (Palacios et al., 2015, Pujadas et al., 2017, Sánchez et al., 2017).

However, it has been well considered to inquire about what would be their effect if they were used in the district of Plaza de la Cruz. For this purpose, CFD simulations of the NOx dispersion were carried out in the Plaza de la Cruz area considering that in an area of about 400 x 400 m^2, photocatalytic material was installed on the sidewalks (Figure 10). If we analyze the relative difference between the concentration around the breathing level of pedestrians and cyclists, obtained in the case of having photocatalytic material against the case of not having it, we can see that the reduction of the maximum concentration of pollutant in Plaza de la Cruz does not reach 6%, and on average it would be between 3 and 4%. In the whole of the area, the average reduction is around 2%. Therefore, the photocatalytic material is not entirely effective in reducing pollution in an urban area, and is clearly less effective than other measures such as traffic restriction.



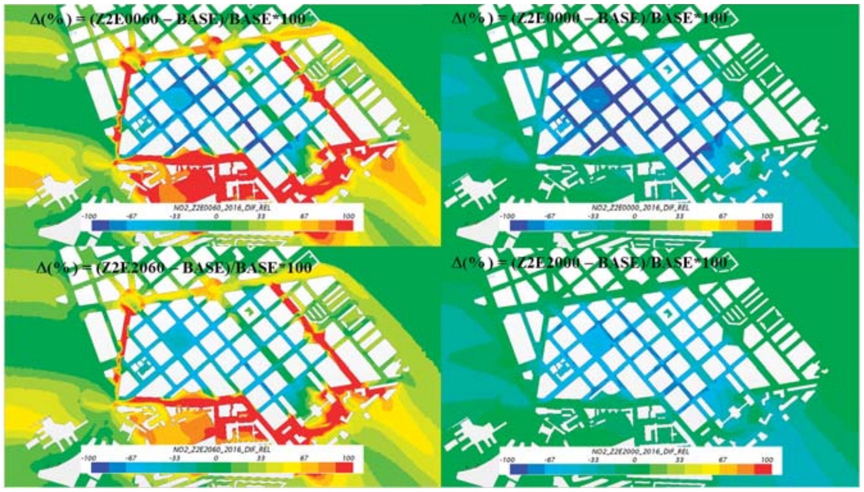


Figure 9. Relative differences of NOx concentration in the District of Plaza de la Cruz estimated for the cases in which the zone indicated in the map above have been applied to different traffic restrictions: traffic reduction 100% (above) and reduction of traffic by 80% (below); and with different redistribution of traffic: with 60% of the traffic diverted to the surrounding avenues (left) and without diverted traffic (right)

Conclusions

The CFD models used fit very reasonably to the data recorded in Pamplona air quality measurement stations and to the data collected in the experimental campaigns carried out in that city, either with fixed or mobile equipment (data from sensors carried by volunteer cyclists). These models show the great spatial variability of the concentration of pollutants within the streets, giving a very high resolution view of the pollution in the city. One of the great novelties of this study is that for the first time in Spain, and almost in the world, it has been possible to use very high resolution CFD models to simulate pollution in a medium size city like Pamplona, which has a huge computational effort. This has helped to detect which streets are the most polluted and at what times more pollution occurs.

At the moment, there is no general criteria that can be established regarding the use of urban vegetation. For each particular case, it is necessary to analyze the impacts that it may suggest on air quality, but also taking into account the thermal comfort, the energy consumption of the buildings or the emissions of VOCs and allergens. In addition, it is necessary to study what type, size and shape of trees and vegetation are better in each case, the most suitable locations within the street or with respect to the road, etc.

Finally, the effect of other measures to reduce pollution has been analyzed, as is the case, of pedestrianizing some non-main streets around Plaza de la Cruz, considering the redistribution of traffic, or the effect of installing photocatalytic pavements in several streets of that district. The first option is much more effective than the second. Traffic restrictions drastically reduce pollution in the affected streets, but can increase it in the surrounding areas if traffic is diverted to them. On the other hand, the reduction of the concentration of NOx at the breathing level of pedestrians due to these photocatalytic pavements is small.

References

Dalton J.S., P.A. Janes, N.G. Jones, J.A. Nicholson, K.R. Hallam, G.C. Allen, 2002. Photocatalytic oxidation of NOx gases using TiO2: a surface spectroscopic approach. Environmental Protection, 120 (2), pp. 415-422.

Lim T.H., S.M. Jeong, S.D. Kim, J. Gyenis, 2000. Photocatalytic decomposition of NO by TiO2 particles. Journal of Photochemistry and Photobiology, 134 (3), pp. 209-217

Parra MA, Santiago JL, F. Martin, A. Martilli, J.M. Santamaría, 2010. A methodology to urban air quality assesment during large time periods of winter using computational fluid dynamic models. Atmospheric Environment 44, 2089-2097.

Palacios M., L. Núñez, M. Pujadas, J. Fernández-Pampillón, M. Germán, B. S. Sánchez, J. L. Santiago, A. Martilli, S. Suárez, B. S. Cabrero, 2015. Estimation Of NOx Deposition Velocities For Selected Commercial Photocatalytic Products. WIT Transactions on The Built Environment. 168, 729-740. DOI 10.2495/SD150642

Pujadas M., M. Palacios, L. Núñez, M. Germán, J. Fernández-Pampillón, B. Sanchez, J.L. Santiago, Benigno Sanchez, R. Muñoz, Félix Moral, Guzmán Arias, 2017. Real scale tests of the depolluting capabilities of a photocatalytic sidewalk pavement and a facade in an urban scenario. 18th International Conference on Harmonisation within Atmospheric Dispersion modelling for regulatory purposes. Póster. Bolonia, Italia

Rivas E., J.L. Santiago, F. Martin, A. Ariño, J.M. Santamaría, J.J. Pons, 2017. Progress in urban air quality assessment: CFD modelling of a whole town in Spain. 18th International Conference on Harmonisation within Atmospheric Dispersion modelling for regulatory purposes. Comunicación oral. Bolonia, Italia.

Sanchez B., J.L. Santiago, A. Martilli, M. Pujadas, M. Palacios, L. Núñez, M. Germán, Benigno Sanchez, R. Muñoz, 2017. CFD modelling of effects on NOx concentration of photocatalytic materials applied to a sidewalk pavement and a brick wall in a real street canyon. 18th International Conference on Harmonisation within Atmospheric Dispersion modelling for regulatory purposes. Póster. Bolonia, Italia.

Santiago JL, Martin F, Martilli A, 2013. A computational fluid dynamic modelling approach to assess the representativeness of urban monitoring station. Science of the Total Environment 454, 61-72.

Santiago JL, Martilli A, Martin F, 2017a. On Dry Deposition Modelling of Atmospheric Pollutants on Vegetation at Microscale: Application to the Impact of Street Vegetation on Air Quality. Boundary-Layer Meteorology 162, 451-474.

Santiago JL, Rivas E, Sanchez B, Buccolieri R, Martin F, 2017b. On the influence of aerodynamics and deposition effects of street vegetation on NOx concentrations at pedestrian level: the case of Plaza de la Cruz neighborhood in Pamplona (Spain). Atmosphere 8(7), 131.

Vranckx S., Vos P, Mahieu B, Janssen S, 2015. Impact of trees on pollutant dispersion in street canyons: A numerical study of the annual average effects in Antwerp, Belgium, Science of The Total Environment 532. DOI10.1016/j.scitotenv.2015.06.032

The impact that changes in the routes' slopes have on cyclists cannot be overlooked when estimating their exposure to pollution. An increase in heart rate can mean that breathing frequency is doubled, so the air intake into the lungs becomes increasingly higher than when at rest or while cycling on flat roads. Combined with the variation in speed, it is clear that the exposure to urban air of a road of a certain length can change significantly depending on the ascending or descending slope of the route. Therefore, just knowing the estimation of pollutants in a given road may not be enough; you also have to consider the average gradient and the direction the cyclists travel. In this regard, the exposure to occasional high concentrations of high air pollution can be detrimental to the health of cyclists and pedestrians, hence the need to carry out studies that investigate these aspects to improve their quality of life.

Conclusions

The use of transport in cities has a significant impact on society, including reducing emissions of greenhouse gases and other pollutants that are harmful to health, as well as an increase in physical activity. However, cyclists (and to a lesser degree pedestrians) are more exposed than other citizens to air pollutants generated by traffic, a fact related to the physical exercise that they carry out, namely the intense exercise undertaken in certain roads with steep slopes, which implies a significant increase in the intake of air pollutants.

Taking into account the environmental and health benefits of active transport, whether it be by foot or by bicycle, it is clear that politicians and municipal managers must be encouraged to develop roads with less contact with motorised traffic, so that cyclists can commute during peak hours without being subjected to high levels of pollution.

In this regard, the Healthy Route Planner developed in the LIFE+RESPIRA project is a very useful tool to help citizens move around through those routes that show a lower level of air pollutants, therefore improving their quality of life.

References

Han X, Naeher LP. (2005). A review of traffic-related air pollution exposure assessment studies in the developing world. Environ Int 32:106–20.

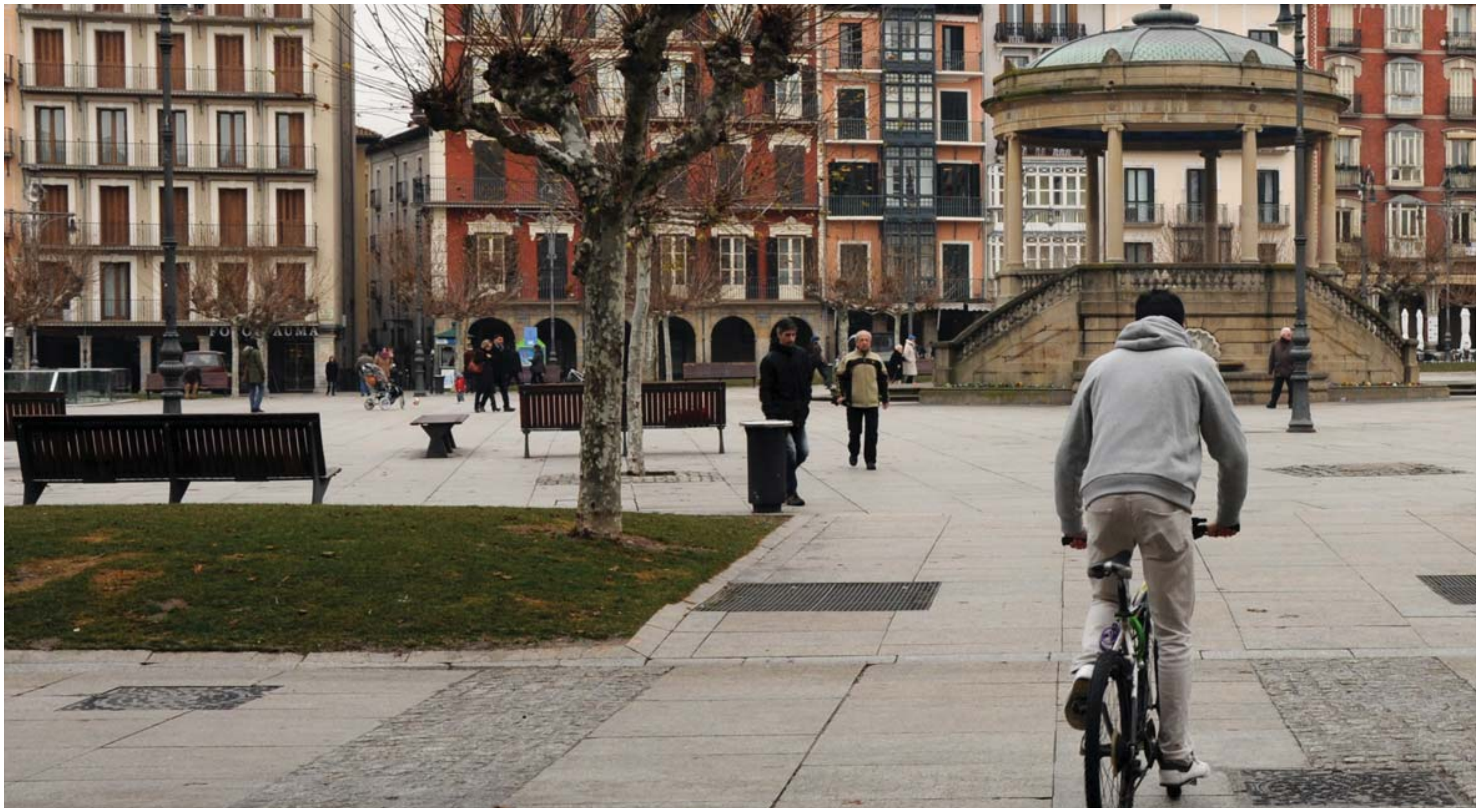
Hoek G, Krishnan RM, Beelen R, Peters A, Ostro B, Brunekreef B, et al. (2013). Long-term air pollution exposure and cardio-respiratory mortality: a review. Environ Heal 12(43).

Int Panis L, de Geus B, Vandenbulcke G, Willems H, Degraeuwe B, Bleux N et al. (2010). Exposure to particulate matter in traffic: a comparison of cyclists and car passengers. Atmos Environ 44: 2263–2270.

Janssen NAH, Hoek G, Simic-Lawson M, Fischer P, Bree L, Brink H, et al. (2011). Black carbon as an additional indicator of adverse health effects of airborne particles compared with PM10 and PM2.5. Environ Health Perspect 119(12):1691–9.

MacNaughton; P.; Melly, S.; Vallarino, J.; Adamkiewicz, G.; and Spengler, J.D. (2014). Impact of bicycle route type on exposure to traffic-related air pollution. Science of the Total Environment 490 (2014) 37–43.

Strak M, Boogaard H, Meliefste K, Oldenwening M, Zuurbier M, Brunekreef B, et al. (2011). Respiratory health effects of ultrafine and fine particle exposure in cyclists. Occup Environ Med 67:118–24.



5. IMPACTS OF URBAN POLLUTION

Social perception of air pollution

The study of individual and social reactions to urban air pollution has been the subject of psychological and social research for more than three decades (Saksena, 2011). In addition to examining the extent to which the reactions of individuals are influenced by different psychological, sociocultural and environmental factors (Williams and Bird, 2003, Simone et al., 2012), researchers have also analysed aspects such as the perception of severity in relation to air pollution (Vanderslice and Peterson, 2014, Liao et al., 2015), the levels of personal annoyance generated (Claeson et al., 2013), the coping strategies developed by citizens (De Boer et al., 1987; Evans et al., 1988) and their use of air quality information (Smallbone, 2012; Radisic et al., 2016).

The understanding of all these type of reactions constitutes an essential element for the management of air quality in cities. In this context, this paper aims to contribute to the design of interventions aimed at producing changes in the individuals' behaviour, both to reduce pollution and to protect against their impacts, helping them to become aware of an aspect as relevant as the air quality.

Table 1. Publications revised to develop the questionnaire.

Methodology used

The results of this study are based on an on-line survey administered to a sample of 242 citizens of the city of Pamplona and two on-line focus groups with 19 citizens. The following dimensions were analysed: subjective evaluation of air quality; attention to air quality; annoyance, sensory experience, symptoms and quality of life; perception of risk; emotional responses; controllability and self-efficacy; behaviour (protection actions, reduction actions and involvement actions) and evaluation of informative materials.

The results of this work have been compared with those obtained in a previous study (Oltra et al., 2015) carried out in four Spanish cities: Barcelona, Madrid, Zaragoza and La Coruña.

The questionnaire was designed ad hoc taking into account the objectives of the study, since no existing instruments were found that met the proposed needs. The development of the questionnaire was based on an exhaustive literature review on the subject (Table 1).

Beliefs and behaviour of the citizens of Pamplona in relation to air pollution

The citizens of Pamplona consider that air quality in their neighbourhoods is good. In general, they report that the city does not face air pollution problems and they comment, for instance, that the city is surrounded by natural areas and therefore cannot be contaminated. Similarly, a majority of participants say they do not pay attention to the air quality when they travel through Pamplona and more than half say they have not felt any annoyance related to air pollution in the last month. In terms of sensory experience, a low percentage of participants affirm to perceive smog (14%), or streets with too much smoke from the car exhausts (15%). Regarding

Empirical studies on perception of pollution	Araban et al., 2013 Brody et al., 2004 Bickerstaff and Walker, 2001 Claeson et al., 2013 De Boer et al., 1987 Deguen et al., 2012 Dixon et al., 2009 Elliott et al., 1999 Howel et al., 2003 Johnson, 2003 Nowka et al., 2011 Simone et al., 2012 Smallbone, 2012 Weber et al., 2000 Zeidner and Shechter, 1988
Previous study with discussion groups	Sala et al., 2014
Previous questionnaires on air pollution	APQ (Deguen et al., 2012)
Other relevant publication	Health Belief Model (Becker, 1974) Dillard et al., 2012

Table 1. Publications revised to develop the questionnaire.

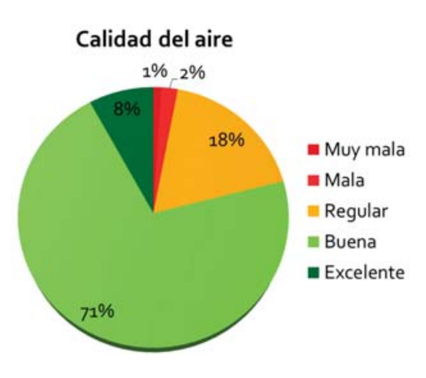


Figure 2. Subjective evaluation of air quality in Pamplona

The degree of awareness that participants have about the risk of contamination in health is high, since 90% of the sample claims to have heard about its effects. Likewise, we found a considerable perception of danger, placing the average at 3.4 on a scale of 1 to 5. However, their knowledge of the specific diseases caused by air pollution is smaller. Regarding the perceived severity of the effects of pollution, half of the sample considers that they are moderate and 41% think they are serious, with a small percentage affirming that they are minor problems. However, 96% of the interviewees consider that these effects will occur in the medium or long term, showing little concern for immediacy.

Although the citizens of Pamplona perceive the health risk derived from air pollution, in general they do not show negative emotions related to this belief. Thus, they show low levels of distress and anger, in addition to considering that air pollution is not really unpleasant. They only show low levels of concern.

Most participants believe they have very little control over their exposure to air pollution. Almost half believe that there is no action they can take to protect themselves from urban air pollution. When asked about possible actions to reduce their exposure, the most frequently mentioned behaviours were "avoiding streets with a large volume of traffic" (29%), followed by " wearing masks" (22%). Even so, very few participants declare to carry out protective behaviours such as avoiding opening windows, avoiding physical exercise outdoors or modifying their leisure habits due to air pollution during the last month. The efficacy associated with protective actions is very low; since they consider that the benefits of self-protection are limited; probably as a result of their idea the pollution in Pamplona is low. In terms of the actions facing the pollution situations, a large percentage showed to ignore it and continue with the activities that were carrying out, reinforcing this notion of little concern and low self control. Very few citizens also admit to carrying out actions to reduce air pollution, such as to discontinue using their cars or rather using public transport.

Regarding information behaviours, participants of Pamplona have reported low levels of information actions and low involvement in air quality issues. In this sense, most of the participants have not looked for information about pollution levels or have ever consulted the levels of the AQI (Air Quality Index). Even so, 55% of them declared to know about the existence of warnings and alerts about air pollution. Television and press are the most popular ways to learn about air quality, far above others such as social networks, which are considered to have less credibility.

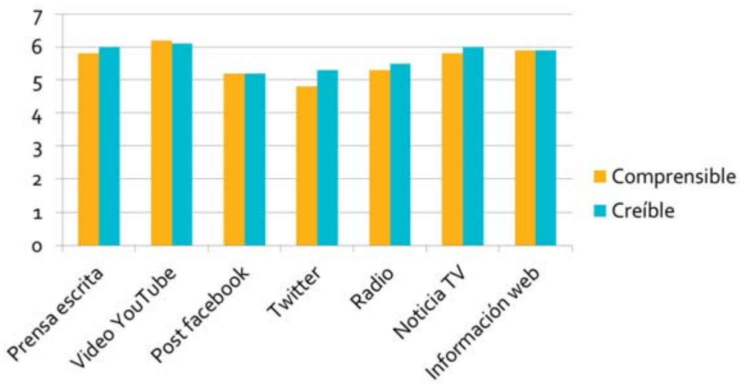


Figure 3. Assessment of sources of information on air quality.

Finally, regarding some of the news generated to disseminate the project, some non-traditional news platforms, such as YouTube, stand out positively, which is very understandable and trustworthy for participants. Even so, traditional media such as the press or television also obtain the most positive evaluation. What seems more complicated is whether this news is able to change the habits of the participants in relation to air pollution.

Differences by socio-demographic profile

Some differences are observed if we take into account the socio-demographic profile of interviewees. For instance, men are less concern about air pollution than women. Men tend to ignore and continue with their activity in a situation of contamination, while women do not. In addition, men report higher levels of self-efficacy, that is; they believe they are more able to protect themselves from air pollution. A lower sensory perception of symptoms was found among men.

Men also stand out positively in information behaviours regarding air quality. Thus, they feel better informed; they are the ones who report to a greater extent having heard or read news about air pollution and also have a greater knowledge of the existence of warnings and alerts. Finally, as regards to the media use, they tend to use the press to obtain information about air pollution.

Taking into account socio-economic level, people on the lowest social scale are those who claim to have less control over their exposure to air pollution. In addition, in terms of emotional responses, are those who report a higher level of distress.

When age factor is taken into account, people who are older are those who have better knowledge of chronic diseases caused by pollution. On the contrary, in terms of knowledge of the existence of warnings and alerts about pollution, the youngest stand out, with a greater knowledge of these alerts. In addition, the youngest also stand out for using the Web and Twitter as a means of information, a possible explanation to their higher awareness of warnings and alerts, as they are often disseminated through the Internet.

Figure 4. Perception of air pollution according to the socio-demographic profile.

In the case of people suffering from a chronic respiratory disease, it is observed that they show greater susceptibility and severity beliefs, paying more attention to air quality than people who do not suffer from such diseases. This higher susceptibility is also observed in the average of suffered symptoms, showing a greater number of symptoms for people with chronic diseases. These participants show a better knowledge of the specific diseases caused by air pollution. They stand out for the use of Facebook as a means of inform themselves about air pollution issues.

Finally, regarding people with children, it is observed that they are the ones who show the greatest concern regarding pollution. These participants declare to use the web to inform themselves about air pollution.

The perception in Pamplona regarding Barcelona, Madrid, La Coruña and Zaragoza

If we compare Pamplona with the other cities studied, the citizens of Pamplona perceive to a greater extent that the air of their city is good or very good, unlike those in Madrid and Barcelona, but also citizens from Zaragoza and La Coruña. This pattern repeats for most of the variables studied: attention to the quality of the air they breathe, annoyance due to air pollution, physical symptoms caused by pollution (such as breathing difficulties, eye irritation or headaches) and impacts on the quality of life. In Pamplona citizens say they pay less attention, are less annoyed, suffer fewer symptoms and have less impact on their quality of life. These differences between the five cities studied are statistically significant.

Likewise, Pamplona presents a lower perception of the risk derived from air pollution than that found in the other four cities. Around 52% of the total number of people interviewed in Pamplona considers that air pollution is quite or very dangerous, a lower percentage than the average of the other four cities, where this figure reaches 80%. There are also differences in the diseases attributed to pollution, being the citizens of Pamplona those who have a lower knowledge about it. In the same way, the citizens of Pamplona consider the effects of pollution as less serious than citizens of other cities. On the other hand, the degree of public awareness about the effects of air pollution on health doesn't show significant differences between Pamplona and the rest of the cities studied. In other words, the citizens of the five cities have heard about the harmful effects of pollution equally. If we look at the emotional responses of citizens, we see that the Pamplona data reflect less concern than in the other four cities, and also less distress. In addition, the participants in Pamplona are the ones that have reported a lower level of anger regarding air pollution.

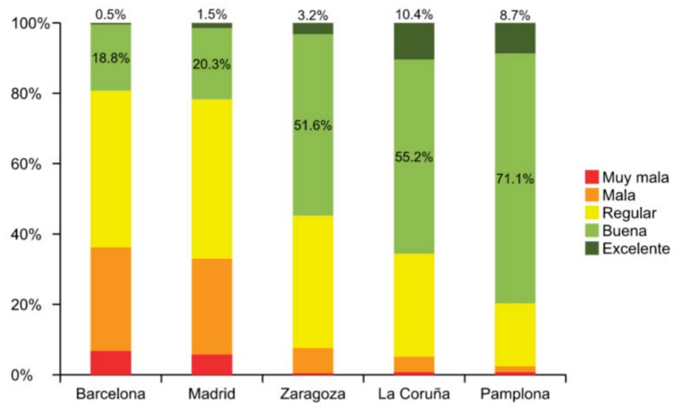


Figure 5. Subjective assessment of air quality in other cities of Spain.

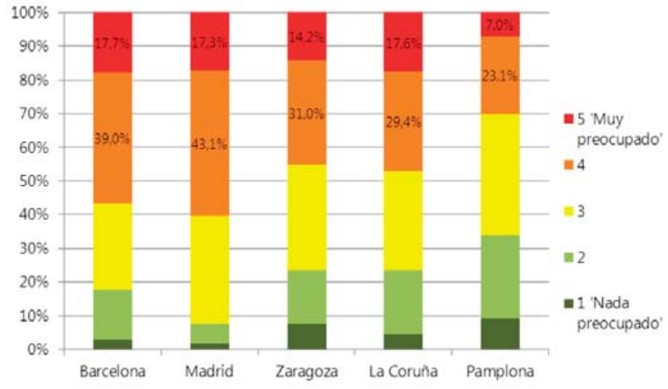


Figure 6. Degree of concern of citizens about air pollution.

In personal self-efficacy, no statistically significant differences were found between Pamplona and the rest of the cities. That is, the citizens of the five cities believe equally that there are no actions that they can carry out in their daily live to protect themselves from pollution. However, when the participants were asked if they spontaneously took any action to protect themselves from pollution, the answers were different between the four cities and Pamplona. In the case of the other four cities, the most repeated action was to wear masks (31%), while in the case of Pamplona the most repeated action was to avoid traffic zones (29%). When asking about the list of concrete actions carried out during the last month (modifying their leisure habits, avoiding physical exercise, staying at home, etc.), the citizens of Pamplona report the lowest rates of implementation.

As regards to whether they stopped using their private vehicles for some time due to air pollution, statistically significant differences are observed between the 5 cities studied. Pamplona is the one that shows a higher percentage (12%). However, the other cities are between 9 and 10%.

Finally, in relation to information behaviours, the citizens of Pamplona are again those that report lower levels, although in general, reduced levels of involvement have been found in the sample as a whole. For example, only 8% of those interviewed in Pamplona, 13% in La Coruña, 19% in Barcelona, 21% in Madrid or 22% in Zaragoza declared to have searched for information on air quality levels in their city through the internet, the press, etc. Regarding the knowledge of warnings and alerts when certain pollution levels are exceeded, in Madrid and Barcelona, for example, close to 70% of those interviewed is aware of the existence of alerts. This percentage is reduced to 60% in Zaragoza, 55% in Pamplona and 52% in La Coruña. These differences between cities are statistically significant. In the case of the AQI consultation, however, the differences exist between Pamplona, Barcelona and La Coruña in relation to Madrid and above all in relation to Zaragoza, where much higher percentages are reported.

Conclusions

Motivating and facilitating individual actions of involvement, reduction and self-protection against the impacts of air pollution should be, along with structural and regulatory measures, one of the fundamental goals of air quality management in cities. Therefore, it is necessary to take into account the psychosocial dimension of air pollution. The reaction of individuals to air pollution is sometimes more complicated than it is assumed. Citizens have certain beliefs, attitudes and behaviours in relation to this environmental problem that, if they are not taken into account, can lead to the failure or inefficiency of certain communication, mitigation and health protection strategies.

The data of this study is intended to be useful in the development of risk communication and public involvement programs of the LIFE + RESPIRA project in the field of urban air pollution in Pamplona with the intention of promoting the change of citizen behaviour.

The results of psychosocial research could contribute to the inclusion of social indicators (arising from the appreciation of the same target population) in the socio-economic assessment of the problem. , These results could also contribute to improve the design and evaluation of the intervention and dissemination strategies. In addition, the inclusion of the social dimension complements the environmental, economic, epidemiological and technological analysis that has been carried out in the project. To sum up, this study supposes an added value to the general objectives of the project.

References

Araban, M., Tavafian, S. S., Motesaddi Zarandi, S., Hidarnia, A. R., Gohari, M. R., Prochaska, J. M., Montazeri, A. (2013). Introducing a new measure for assessing self-efficacy in response to air pollution hazards for pregnant women. Journal of Environmental Health Science & Engineering, 11(1), 16. https://doi.org/10.1186/2052-336X-11-16.

Becker, M. H. (1974). The health belief model and personal health behavior. Slack, 2(4).

Bickerstaff, K., & Walker, G. (2001). Public understandings of air pollution: The "localisation" of environmental risk. Global Environmental Change, 11(2), 133–145. https://doi.org/10.1016/S0959-3780(00)00063-7.

Brody, S. D., Peck, B. M., & Highfield, W. E. (2004). Examining localized patterns of air quality perception in Texas: a spatial and statistical analysis. Risk Analysis : An Official Publication of the Society for Risk Analysis, 24(6), 1561–74. https://doi.org/10.1111/j.0272-4332.2004.00550.x.

Claeson, A. S., Lidén, E., Nordin, M., & Nordin, S. (2013). The role of perceived pollution and health risk perception in annoyance and health symptoms: A population-based study of odorous air pollution. International Archives of Occupational and Environmental Health, 86(3), 367–374. https://doi.org/10.1007/s00420-012-0770-8.

De Boer, J., Van der Linden, J., Van der Fligt, J. (1987). De Boer et al. 1987. Air pollution, annoyance and coping.pdf. In Environmental Annoyance: Characterization, Measurement and Control. Koelega editor.

Deguen, S., Ségala, C., Pédrono, G., & Mesbah, M. (2012). A new air quality perception scale for global assessment of air pollution health effects. Risk Analysis : An Official Publication of the Society for Risk Analysis, 32(12), 2043–54. https://doi.org/10.1111/j.1539-6924.2012.01862.x.

Dillard, A. J., Ferrer, R. a, Ubel, P. a, & Fagerlin, A. (2012). Risk perception measures' associations with behavior intentions, affect, and cognition following colon cancer screening messages. Health Psychology : Official Journal of the Division of Health Psychology, American Psychological Association, 31(1), 106–13. https://doi.org/10.1037/a0024787.

Dixon, J. K., Hendrickson, K. C., Ercolano, E., Quackenbush, R., & Dixon, J. P. (2009). The Environmental Health Engagement Profile: What People Think and Do about Environmental Health. Public Health Nursing, 26(5), 460–473. https://doi.org/10.1111/j.1525-1446.2009.00804.x.

Elliott, S. J., Cole, D. C., Krueger, P., Voorberg, N., & Wakefield, S. (1999). The power of perception: health risk attributed to air pollution in an urban industrial neighbourhood. Risk Anal, 19(4), 621–634.
https://doi.org/10.1111/j.1539-6924.1999.tb00433.x.

Evans, G. W., Colome, S. D., & Shearer, D. F. (1988). Psychological reactions to air pollution. Environmental Research, 45(1), 1–15.
https://doi.org/10.1016/S0013-9351(88)80002-1.

Howel, D., Moffatt, S., Bush, J., Dunn, C. E., & Prince, H. (2003). Public views on the links between air pollution and health in Northeast England. Environmental Research, 91(3), 163–171.

Johnson, B. B. (2003). Communicating air quality information: experimental evaluation of alternative formats. Risk Anal, 23(1), 91–103.

Liao, X., Tu, H., Maddock, J. E., Fan, S., Lan, G., Wu, Y., Lu, Y. (2015). Residents' perception of air quality, pollution sources, and air pollution control in Nanchang, China. Atmospheric Pollution Research, 6(5), 835–841. https://-doi.org/10.5094/APR.2015.092.

Nowka, M. R., Bard, R. L., Rubenfire, M., Jackson, E. a, & Brook, R. D. (2011). Patient awareness of the risks for heart disease posed by air pollution. Progress in Cardiovascular Diseases, 53(5), 379–84. https://doi.org/10.1016/j.pcad.2010.12.003.

Radisic, S., Newbold, K. B., Eyles, J., & Williams, A. (2016). Factors influencing health behaviours in response to the air quality health index: a cross-sectional study in Hamilton, Canada. Environmental Health Review, 59(1), 17–29. https://doi.org/10.5864/d2016-002.

Saksena, S. (2011). Public Perceptions of Urban Air Pollution Risks. Risk, Hazards & Crisis in Public Policy, 2(1), 19–37. https://doi.org/10.2202/1944-4079.1075.

Sala, R., Oltra, C., & Gonçalves, L. (2014). Percepción Pública de la Contaminación Atmosférica Urbana: Un Análisis Exploratorio.

Simone, D., Eyles, J., Newbold, K. B., Kitchen, P., & Williams, A. (2012). Air Quality in Hamilton: Who is Concerned? Perceptions from Three Neighbourhoods. Social Indicators Research, 108(2), 239–255. https://doi.org/10.1007/s11205-012-0064-2.

Smallbone, K. (2012). Individuals ' Interpretation of Air Quality Information. Retrieved from http://eprints.brighton.ac.uk/13154/.

Weber, J. M., Hair, J. F., & Fowler, C. R. (2000). Developing a measure of perceived environmental risk. Journal of Environmental Education, 32(1), 28–35. https://doi.org/DOI:10.1080/00958960009598669.

Williams, I. D., & Bird, a. (2003). Public perceptions of air quality and quality of life in urban and suburban areas of London. Journal of Environmental Monitoring, 5(2), 253–259. https://doi.org/10.1039/b209473h.

Zeidner, M., & Shechter, M. (1988). Psychological responses to air pollution: Some personality and demographic correlates. Journal of Environmental Psychology, 8(3), 191–208. https://doi.org/10.1016/S0272-4944(88)80009-4.

Economic valuation of the impacts caused by air pollution

Air pollution in the cities has important effects on the health of its inhabitants, which basically result in two types of conditions: on the one hand, incidences in morbidity, especially cardiovascular and respiratory diseases, and on the other hand, increase in premature mortality, analyzed in terms of reduced life expectancy.

These effects lead to direct economic costs, such as health expenses, but also indirect or external costs in the form of welfare loss. Therefore, the value of the damage associated with the deterioration of health is made up of three different components:

1) The cost of treatment of diseases (medication and equipment).

2) The opportunity cost derived from sick leave, which includes both the value of productivity lost due to absenteeism or lower performance, and the value of leisure time sacrificed as a result of the illness.

3) The loss of well-being caused to relatives and patients.

Regarding the identification of specific pollutants that cause health impacts, as recognized by recent studies, such as the one published by the European Environment Agency in 2017 (EEA, 2017), the most important effects are caused by small particles - diameter less than 2.5 microns - or $PM_{2.5}$. However, an important part of the health conditions are caused by the emissions of nitrogen oxides, such as NO_2, emissions that are associated with traffic almost entirely and therefore are those that have been investigated in the LIFE+RESPIRA project.

Study of the impact route

To estimate the damage caused by air pollution, it is necessary to apply a complete methodological process known as an impact pathway. This methodology offers an analytical framework capable of transforming the information related to the emission of different pollutants into a common unit: monetary units. For this, it is necessary to develop a methodological process that consists in following the pollutants throughout all the phases, from their emission until they reach the receptors, causing them damage. The following stages can be distinguished:

a) Emission of pollutants. This study focuses on the emission of NO_2.

b) Atmospheric concentration: this consists in estimating the change in environmental quality derived from an increase in emissions. For this, atmospheric dispersion models are used.

c) Exposure of the population to the concentrations of NO_2 produced. For this it is necessary to know the spatial and age distribution of the city's population.

d) Environmental impact, whose estimation is carried out through the application of exposure-response functions that allow determination of the increase in the health endpoints caused by an increase in the atmospheric concentration of the pollutant.

e) Damage caused, which consists in estimating the value that the population attributes to the impacts caused by pollution. This estimation makes it possible to determine the deterioration of the wellbeing of the population as a consequence of the variation in the atmospheric quality induced by the pollution of transport in the urban environment.

The project's modelling activities have resulted in detailed maps of NO_2 concentration throughout the city of Pamplona. Likewise, using the data of the Municipal Census of Inhabitants, it gives you the distribution of the population of the city of Pamplona in a grid of cells 100 x 100 m, as well as its distribution by age. The base incidence of diseases related to exposure to NO_2 is also known or estimated.

For the quantification of the impacts, the exposure-response functions proposed by the World Health Organization (WHO, 2013) have been used to estimate the effects on health.

The process of calculating these impacts follows this general formula:

$$I = C \times P \times R \times CRF \times V$$

Meaning:

I: Impact expressed in number of additional cases

Ci: Concentration of the pollutant

P: Population at risk

R: Incidence ratio

CRF: Concentration response function or change in incidence per unit of concentration

V: Monetary valuation of the impact on health

The concentration response functions used are those proposed by the WHO in the HRAPIE project and are the following:

Effects of long-term exposure to NO_2 on mortality in the population over 30 years of age. The WHO experts recommend the application of a linear CRF function that corresponds to a relative risk (RR) of 1.055 (confidence interval 1.031-1.08) for every 10 $\mu g/m^3$ of annual mean concentration of NO_2. This RR value is obtained from the meta-analysis carried out by Hoek et al. (2013) and considers a threshold concentration of 20 $\mu g/m^3$. The mortality rate has been obtained from the Statistical Institute of Navarra for the province of Navarra and is 0.89% for the year 2015.
(http://www.navarra.es/AppsExt/GN.InstitutoEstadistica.Web/informacionestadistica.aspx?R=1&E=1).

Effects of long-term exposure to NO_2 on the onset of bronchitis symptoms in asthmatic children between the ages of 5 and 14 years. For the consideration of these effects, the WHO recommends the use of the results of the study by McConnell et al. (2003), which calculates a RR of 1.021 (confidence interval 0.99-1.06) for every 1 $\mu g/m^3$ of NO_2. The percentage of asthmatic children in the city of Pamplona has been obtained from the data of the Primary Care Service of the Navarra Health Service for each of the health areas of the city. The prevalence of bronchitis symptoms in asthmatic children has been considered as an average of the values obtained in the studies of Migliore et al. (2009) (21.1%) and McConnell et al. (2003) (38.7%).

Effects of short-term exposure to increased levels of NO_2 in mortality. To study these effects, WHO recommends using the results of the APHEA-2 project (Samoli et al., 2006) covering 30 European cities and obtaining an RR value of 1.0027 (confidence interval 1.0026-1.0038) for every 10 $\mu g/m^3$ of daily maximum 1-hour mean concentration of NO_2.

Effects of short-term exposure to increased concentrations of NO_2 in hospital admissions for respiratory diseases. The WHO recommends the use of RR values from the study by Anderson et al. (2007) of 1.018 (confidence interval 1.0115-1.0245) per 10 $\mu g/m^3$ of average 24-hour mean concentration. The basic value for hospidtalizations for respiratory diseases has been obtained from the database of the WHO European Hospital Morbidity Database (http://data.euro.who.int/hmdb/) and is 1.26% for Spain.

Experts in the HRAPIE project classified the recommended exposure-response functions (CRFs) in two categories:

• Group A: CRFs that allow a robust quantification of the effects. The last two functions are included in this category.

• Group B: CRF for which there is more uncertainty about the accuracy of the data used to quantify the effects. The first two functions are included in this category.

In this evaluation both the functions of group A and those of group B have been used, so that a limited set of impacts based on the sum of the functions of Group A * has been calculated first and then an extended set of impacts based on the sum of the functions of Group A * and Group B *.

The monetary valuation of these impacts is done by multiplying the impacts in physical terms by the unitary monetary value of each condition to health. These unit values aim to capture the total economic impact of health impacts and include health costs, lost productivity and aversion to poor health or reduced life expectancy. The monetary values used in this study are those used by Holland in the cost benefit analysis of the Clean Air Package of the European Commission (Holland, 2014). These values, updated to Euros in 2015 using the variation of the CPI, are shown in Table 1.

Table 1. Monetary values of health conditions used in this study

Impact	**Coste unitario**	**Unidad**
Mortality	68143,70	$Euros_{2015}$ / year of life lost
Bronchitis	694,43	$Euros_{2015}$/case
Hospital admissions	2621,82	$Euros_{2015}$/case

Costs associated with pollution levels

The results obtained show that, in 2015, around 7% of the population of Pamplona has been exposed to levels of nitrogen oxides contamination above the maximum levels of 40 $\mu g/m^3$ recommended both by the European Union and by the WHO.

This exposure leads to the appearance of various health effects that have been quantified, for the conditions existing in 2015, to 18 years of life lost due to exposure to high levels of pollution in the city, 120 hospital admissions for respiratory diseases, 152 additional cases of bronchitis in asthmatic children and 60 years of life lost due to long-term exposure to these increased levels of contamination (Fig. 1). The results of the uncertainty analysis performed are shown in the graph as error bars.

These effects translate into medical costs and loss of well-being that are called external costs or externalities. The results obtained, as can be seen in Figure 2, amount to a total of € 1.57 million (1.04-2.19) if we only take into account the effects considered as A * (green in the graphs), and a total of € 5.7 million (5.62-8.27) if we consider all the effects. The most important external costs are due to the reduction in life expectancy followed by hospital admissions due to respiratory problems and cases of bronchitis in asthmatic children.

External costs due to health effects are distributed spatially as shown in Figure 3 and are higher in areas where there is a higher concentration of pollutants and where the population density is higher.

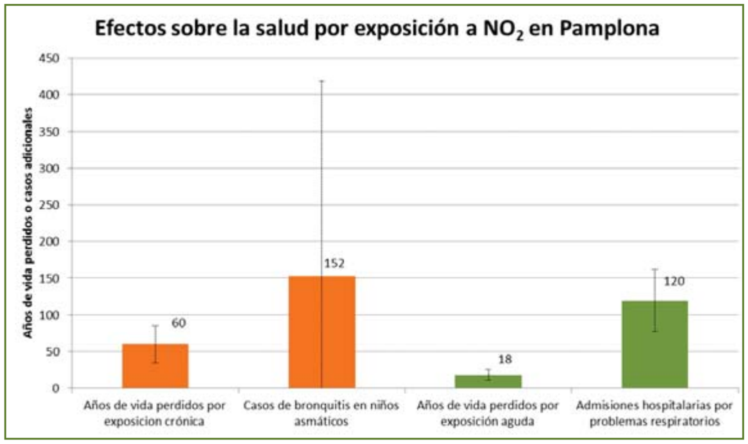


Figure 1. Effects on health due to exposure to .NO_2.

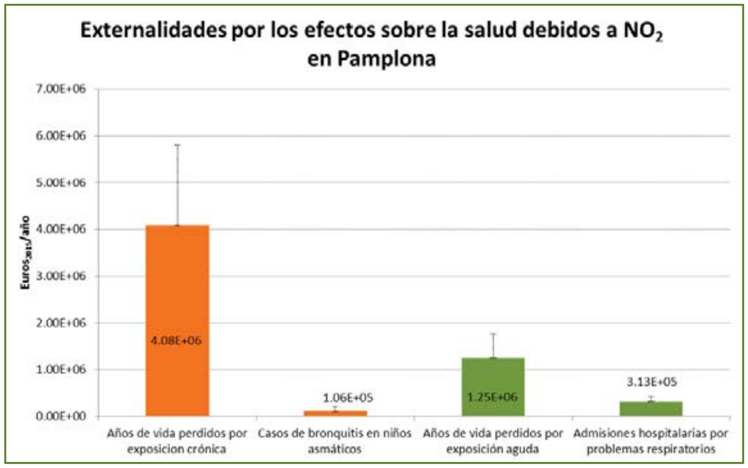


Figure 2. External costs due to the health effects of NO_2.

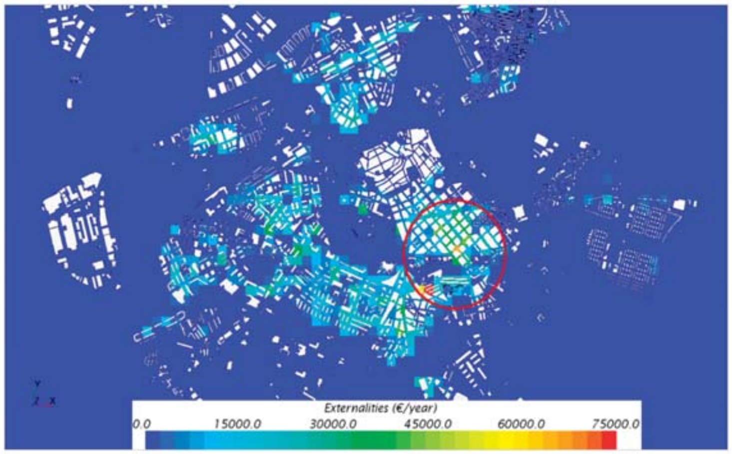


Figure 3. Distribution of external costs calculated.

In this area where external costs are higher, the effects of the measures explored in this project to reduce urban pollution have been quantified (chapter 4). These measures are the following:

- Installation of urban trees in one of the streets.

- Installation of photo-catalytic pavements.

- Redistribution of traffic to avoid these more densely populated areas.

The introduction of urban trees in one of the streets in the area showed very similar external cost results. This is because in addition to reducing contamination by deposit, the trees affect the vertical and horizontal transport of the pollutant and that this aerodynamic effect can, under certain conditions, be more important than the deposit effect. The correct choice of the vegetation layout and the chosen species are crucial to achieve the desired mitigation effects.

The installation of photocatalytic pavements on the footpaths of this area of the city resulted in the reduction of the concentration of NO_2 in the area, with a corresponding reduction in the effects on health and the associated external costs of 2%.

The traffic redistribution scenarios analyzed consisted of cutting the total or partial traffic in this area of the city and its total or partial redistribution in the surrounding streets. The results showed a very important potential for reducing impacts of up to 58% when the traffic in a large area of this area of the city was totally eliminated and it was not redistributed in the surrounding areas. When this traffic is redistributed through other streets and these are densely populated, the results show greater impacts on health. Therefore, it is important to design with care these measures of redistribution of traffic to prevent it from accumulating in nearby streets, generating undesired effects.

Conclusions

The results obtained from the quantification of impacts of NO_2 emissions by road traffic carried out in LIFE + RESPIRA show that around 7% of the citizens of Pamplona have been exposed in 2015 to levels of nitrogen oxides contamination above of the maximum levels of 40 $\mu g/m^3$ recommended both by the European Union and by the WHO. This caused important impacts on health, which in economic terms represent a loss of between €1,570,000 and €5,750,000.

The results obtained from the analysis of the mitigation measures show that these measures, if they are well designed, improve the welfare of the population of Pamplona by reducing health conditions and associated external costs.

References

Anderson HR, RW Atkinson SA Bremner J Carrington J Peacock. Quantitative systematic review of short term associations between ambient air pollution (particulate matter, ozone, nitrogen dioxide, sulphur dioxide and carbon monoxide), and mortality and morbidity. Contract number: 0020017 Report to Department of Health revised following first review June 2007 Division of Community Health Sciences St George's, University of London Cranmer Terrace LONDON SW17 0RE.
(https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/215975/dh_121202.pdf accessed January 2018).

European Environment Agency, 2017. Air quality in Europe — 2017 report. EEA Report No 13/2017. ISBN 978-92-9213-920-9. ISSN 1725-9177. doi:10.2800/358908.

Hoek Gerard, Ranjini M Krishnan, Rob Beelen, Annette Peters, Bart Ostro, Bert Brunekreef and Joel D Kaufman. Long-term air pollution exposure and cardio- respiratory mortality: a review. Environmental Health 2013, 12:43. http://www.ehjournal.net/content/12/1/43.

Holland, M. Cost-benefit Analysis of Final Policy Scenarios for the EU Clean Air package. Version 2 Corresponding to IIASA TSAP report #11, version 2a. October 2014. (http://ec.europa.eu/environment/air/pdf/TSAP%20CBA.pdf
accessed January 2018).

Holland, M. Cost-benefit Analysis of Final Policy Scenarios for the EU Clean Air package. Version 2 Corresponding to IIASA TSAP report #11, version 2a. October 2014. (http://ec.europa.eu/environment/air/pdf/TSAP%20CBA.pdf
accessed January 2018).

McConnell, R., Berhane K, Gilliland F, Molitor J, Thomas D, Lurmann F, Avol E, Gauderman WJ, Peters JM. Prospective study of air pollution and bronchitic symptoms in children with asthma. Am J Respir Crit Care Med. 2003 Oct 1;168(7):790-7.

Migliore, Enrica, Giovanna Berti, Claudia Galassi, Neil Pearce, Francesco Forastiere, Roberto Calabrese, Lucio Armenio, Annibale Biggeri, Luigi Bisanti, Massimiliano Bugiani, Ennio Cadum, Elisabetta Chellini, Valerio Dell'Orco, Gabriele Giannella, Piersante Sestini, Giuseppe Corbo, Riccardo Pistelli, Giovanni Viegi, Giovannino Ciccone and SIDRIA-2 Collaborative Group. Respiratory symptoms in children living near busy roads and their relationship to vehicular traffic: results of an Italian multicenter study (SIDRIA 2). Environmental Health 2009, 8:27 doi:10.1186/1476-069X-8-27.

Samoli E., E. Aga, G. Touloumi, K. Nisiotis, B. Forsberg, A. Lefranc, J. Pekkanen, B. Wojtyniak, C. Schindler, E. Niciu, R. Brunstein, M. Dodič Fikfak, J. Schwartz, K. Katsouyanni. Short-term effects of nitrogen dioxide on mortality: an analysis within the APHEA project. European Respiratory Journal 2006 27: 1129-1138; DOI: 10.1183/09031936.06.00143905

WHO, 2013. World Health Organization. Regional Office for Europe. Health risks of air pollution in Europe-HRAPIE project. Recommendations for concentration-response functions for cost-benefit analysis of particulate matter, ozone and nitrogen dioxide. 2013. Disponible en:
http://www.euro.who.int/__data/assets/pdf_file/0006/238956/Health_risks_air_pollution_HRAPIE_project.pdf?ua=1

6. URBAN SUSTAINABILITY AND MOBILITY

Depiction of the cycling mobility in Pamplona

Cities and bicycles

When characterising the cycling mobility of a city, it's just a question of seeing if it is really useful, by answering a series of essential questions about the bicycle users and the journeys they make.

What you basically want to identify is the number of cyclists that ride along the city roads on a daily basis, how many journeys they make, who the cyclists are, their profiles and what characteristics they have, what type of trips they take, when they ride (hourly and seasonal distribution), and their typical routes.

ELEMENTS AND METHODOLOGY FOR CHARACTERIZING

• Determining the number of cyclists and trips by bicycle

One of the major concerns for managers when characterising mobility is understanding the volume of regular cyclists within the municipal, or the number of trips they make throughout the day. Having access to any of this data, or even knowing the percentage of journeys out of the total journeys made in all modes of transport in the city would provide a very clear indication on the weight of cyclist mobility in the metropolitan area.

However, despite its importance and apparent simplicity, there is no easy way of accessing this information, as in this day and age, acquiring it would mean polling the whole population. These are the so-called "household surveys on mobility" or, the shortened form "mobility surveys".

These works are complex and costly to tackle, as the survey universe is the entire population being studied and therefore the sample is very large. Furthermore, mobility surveys are usually carried out stratified by urban areas of homogeneous behaviour known as "transport areas", which makes the sample sizes increase considerably, with the aim of having representative results for each area.

Conducting household surveys usually involves questionnaires with a host of questions, which demands a lot of time from each surveyed household.

In the particular case of cyclist mobility, given that this means of transport only makes up a fraction of the trips made overall, it is easy for the modal split share to fall below the calculated margin of error for the survey, which poses an added challenge.

All this means that this type of work is extremely costly and only in certain occasions do public bodies (usually the City Councils or Consortiums responsible for public transport) consider doing them (Pazos, 2005).

• Determining the cyclist profile

To better understand the characteristics of cyclists, you can turn to a wider range of sources than in the previous case. First of all, information can be extracted from the mobility surveys themselves, as they collect a lot of personal information about the respondents in each household. Aspects such as age, gender, education and work activity are always an integral part of any questionnaire of this type.

You can also obtain this information through more specific surveys, aimed exclusively at cyclists in the city. In this case, the type of operation becomes easier, since the survey universe is a much smaller population (people who travel by bicycle in the city), and the sample size is therefore easier to manage. However, calculating this parameter can be a problem if global data on urban cyclists is not available.

Lastly, you can also obtain a very basic characterisation of cyclists through other methods, not specifically intended for this purpose, such as bicycle counts. Particularly when these are carried out manually, it is possible to collect information not only on transit points and direction of traffic, but also on the cyclists themselves, at least recording the gender and an approximate age to large groups, for example: children, young people, adults and the elderly.

Determining the reason for travel

The travel motive is another key aspect when it comes to understanding mobility in any means of transport, and cycling is no exception. There are two ways of determining the reason for travel: the purpose of the trip (that is, commuting for educational or work purposes, for leisure, shopping etc.) or the reasons that justify choosing a particular means of transport over another (for speed, economy, health and safety etc.).

Again, the best way to collect this information is turning to surveys, whether they are general mobility surveys or specifically targeted at cyclists (where these types of questions are always included). The reason for travel can sometimes be gathered directly from the place where the survey (or any other activity to analyse mobility) is being conducted, such as bicycle counts or tallying the number of parked bicycles. For example, if any of these activities are carried out at a school or university, you can determine, without much margin of error, that the travel motive is studying.

Determining the time of trips

Another particular feature when analysing cycling mobility is the time of travel. Just like all mobility combined has peak travel periods, cyclists are also subject to the same peak periods.

In principle, you can see a very skewed distributed of trips, according to the time of year. Therefore, you can identify seasonal cycles that are linked to weather conditions (Nosal and Miranda-Moreno, 2014), holiday periods, specific days of the week, (particularly among working days and holidays) and to the time of day (night to day, with morning and afternoon peak travel periods, etc.)

You can obtain information in this regard through mobility surveys, cycling questionnaires and bicycle counts. By properly designing the survey questions and outlining bicycle count models, it isn't difficult to extract the necessary data to obtain seasonal, weekly and hourly distributions of trips.

Determining the routes

To conclude, the last of the big questions about urban cycling mobility is understanding where cyclists travel, that is, which routes they take through the city each day.

This is undoubtedly one of the aspects of greatest interest for the municipal mobility managers with regards to forecasting road infrastructures and other measures.

There are a variety of ways to obtain information on this matter. Firstly, one could turn to the surveys again (both general mobility surveys or those specifically targeted at cyclists). However, the data collected from these is in most cases confined to generic information about origins and destinations of the trips, which provides a matrix of trips by neighbourhood or area of the city, but without the specific streets where they are riding.

The following set of sources is composed of the different types of bicycle counters: manual counts, pneumatic tube counters, video cameras (Zangenehpour et al., 2015). Depending on the technique used, the counting model must be specially designed to make the most of the work being carried out.

For example, manual counts can collect the largest amount of data from a single point, but given that they are so costly (due to the large amount of labour required), it is inconceivable to repeat them on a large scale or on a regular basis. On the other hand, pneumatic sensors can stay on the road for a long time, at any time of day and in more adverse weather conditions, (although they only provide data on the number of transits, and very likely not across the whole road, but rather only a small section of it).

In addition to bicycle counts, associated with the new technologies, other systems have been developed whereby the cyclists carry a type of device, for example a smartphone, with a GPS system which is able to transmit the location through a telephone card. This way, their movements are automatically uploaded onto a large database.

Characterising the cycling mobility in Pamplona

Having reviewed the points that need to be answered in order to characterise cycling mobility in the city, together with the methodological tools that enable us to do so, we will now review the different works carried out in Pamplona in regards to that matter.

Mobility surveys

Over the last quarter of a century several works have been carried out in the metropolitan area of Pamplona, which fit the profile of what we consider to be a mobility survey (Table 1). Firstly, there was a study carried out externally by TEMA Grupo Consultor S.A. on urban transport mobility in the Pamplona comarca, called the "Estudio de Movilidad en relación con el transporte urbano en la Comarca de Pamplona", (Government of Navarre, 1977).

This study was based on a mobility survey with a sample of 2,350 households (including 7,537 residents), conducted among the whole of the Pamplona comarca region in November 1996.

For its part, in 2004, the City Council of Pamplona commissioned a household survey as part of the "Pacto de Movilidad", which is a mobility pact that was confined to the municipal level of the capital (City Council of Pamplona, 2005a), and also for the drafting of the "Plan de Ciclabilidad" (City Council of Pamplona, 2005b), a cycling mobility plan of the city.

A year later, in 2005, these studies were extended through a telephone survey conducted among the rest of the municipalities of the comarca (Government of Navarre, 2006). Although this operation managed to cover the geographical area of interest in order to compare the results with those obtained almost a decade earlier, neither process was methodologically robust, as the telephone survey was only conducted on people who were at home at the time of call, and also due to its short duration, they found that that the number of trips recalled were overtly lower.

The outcomes of these new studies, brought about the "Movilidad en relación con el transporte urbano en la Comarca de Pamplona 2006" (The Urban Transport Mobility in the Pamplona Comarca 2006) report, which was the fundamental basis for the drafting of the "Plan de Movilidad Urbana Sostenible de la Comarca de Pamplona" (Government of Navarre, 2008), an urban mobility plan for the Pamplona region, which was never approved.

Finally, in 2013, the last household survey was conducted, in this case commissioned by the Pamplona District Mancomunidad Association (2014), which is the most comprehensive and ambitious one conducted to date.

The fieldwork, carried out by the company COTESA, questioned a total 4,348 households, in which 11,363 people resideded.

YEAR	ENTITY	AREA	MSAMPLE
1996	Navarre Government	Regional / comarcal	2,350 households
2004	City Council of Pamplona	Pamplona	1,000 households
2005	Navarre Government	Regional / comarcal (not including Pamplona)	708 households
2013	Pamplona District Mancomunidad	Regional / comarcal	4,348 households

Table 1. Mobility surveys conducted in the Pamplona Region.

In short, it can be concluded that of the three mobility surveys carried out in the Pamplona Comarca region, the ones in 1996 and 2013 were methodologically sound and, therefore, their results are comparable with each other. While those carried out in 2004 and 2005 were not, except for the City Council of Pamplona.

When combining all the analysed household surveys, only the one carried out in 2004 by the City Council of Pamplona and the recent one in 2013 were able to provide information on the number of daily trips made by bicycle. The 1996 household survey did not disaggregate this means of transport (which is a significant point in its own right) and the survey conducted on the whole region in 2005 extracted such a small percentage of trips that it didn't even provide any information.

Cyclist surveys

The interest towards studying cycling mobility and the need to understand how the development is being carried out in Pamplona led to various surveys (specifically about this means of transport) to be conducted in the last four years (Table 2).

The pioneer, entitled "Estudio del Perfil del Ciclista Urbano de Pamplona" (a study on Pamplona's urban cyclist profiles) was developed by Xabier Aquerreta in 2013. The author of this work and member of the AMTS (an association of healthy forms of transport), conducted 420 face-to-face surveys with a comprehensive questionnaire that gives us a first glimpse at cycling mobility inside the city.

It is highly significant that this work (which we later saw to be so crucial), was not carried out or promoted by the municipal authorities, but rather stemming from civil society, which is seemingly more concerned about these issues than the City Council itself.

A couple of years later, and again out of the public sphere, the LIFE+RESPIRA project gave rise to an online study entitled "Encuesta a ciclistas urbanos de Pamplona" (a survey of urban cyclists of Pamplona). The work focuses on a questionnaire, that managed to collect 473 responses between 2015 and the beginning of 2016 and had 80 questions, making it very comprehensive.

To contextualize the data side by side, the same questionnaire was carried out, adapted to cyclists in the rest of Spain, which was disseminated with the collaboration of ConBici and other associations.

That same year (2015), the City Council of Pamplona, conducted a survey on cyclists through The Bicycle Observatory. It was a short questionnaire, with only 11 questions, that was answered by 259 people.

The scarce content of the survey and the very small number of responses that were obtained from it, makes one consider this work not to have provided any relevant information at all towards understanding the cycling mobility in Pamplona.

Once again, the City Council of Pamplona carried out more work in 2017, entitled "Encuesta sobre hábitos de movilidad y valoración de la infraestructura ciclista actual" (a survey about mobility habits and evaluation of the current cycling infrastructure), where a total of 1,021 people participated, answering the questionnaire through different means (50% online and 50% face-to-face).

The survey has some interesting points, like the fact that it managed to achieve a very high number of responses and it offers us a new perspective on cyclist mobility, almost two years after the previous survey and at a time when the use of this means of transport in the streets of the city saw a palpable increase.

The design is beset with significant methodological errors, since it is neither a general mobility survey (as is demonstrated by the fact that there were more than 30% of people who said they usually commuted by bicycle in the city), nor is it cyclist survey, given that 32.5% said that they never cycled. It therefore places it in no man's land, and altogether of little use for this reason.

Nevertheless, if the answers that are solely related to cyclists were to be extracted, they could be used as a specific survey for this group of citizens, and their data would therefore be similar to that from the previously mentioned studies.

YEAR	ENTITY	SRVEYS	NUMBER OF QUEESTIONS
2013	Xabier Aquerreta	420	-
2015-2016	LIFE+RESPIRA	473	80
2015	City Council of Pamplona	259	11
2017	City Council of Pamplona	1021	26

Table 2. Cyclist surveys conducted in the Pamplona Region.

Surveys in commute attractor destinations.

The interest towards studying metropolitan mobility has led to the creation of several surveys in recent years. They were conducted in some of the main attractor destinations and were about what is known as "obligatory mobility", in other words, trips that are made for educational or work purposes. These specific surveys are without a doubt, another important source to take into account.

The first survey to be highlighted was carried out at the Public University of Navarre in 2009 as part of its Sustainable Mobility Plan. A total of 269 students and 110 employees of the entity completed the 20-question survey.

The second survey that should be mentioned is the one promoted by an urban mobility plan from the Navarre University ("Sustainable Mobility Plan of the University of Navarra" (2012)). The university population back then was 10,635 people (86% students, 8% administration and service staff and 6% faculty). A face-to-face survey with 14 questions was compiled, that enabled a characterisation of mobility at the mentioned campus. The survey was conducted in December 2010, obtaining a total of 631 completed questionnaires, with 92% by students.

Thirdly, it is worth highlighting the realisation of a survey about work commuting habits, which was conducted in 2013 on employees of the VOLKSWAGEN plant in Navarre. This company has one of the highest number of employees in the Autonomous Community of Navarre and is located in the Landaben industrial estate, just a few kilometres from Pamplona. The questionnaire was part of the diagnostic phase of a sustainability plan for commutes to work (Sustainable Mobility Plan) and consisted of 23 questions. It was conducted face-to-face on 4,500 workers, a figure that represents 38% of the workforce (1,700 employees).

The last survey to be mentioned has two special features. It specialised in secondary school students and it was carried out on the initiative of LIFE+RESPIRA. The mobility survey was conducted online on 2,500 schoolchildren between the ages of 6 and 16, and over 600 families belonging to 10 educational centres. There were 34 questions in the schoolchildren's questionnaire and 25 questions for the family one. While there was a satisfactory number of questionnaires achieved, it is however pending approval as to whether it reflects the real situation of the comarca region. We know that the Pamplona District Mancomunidad Association is working in this direction.

The contribution of all this work towards understanding the cycling mobility in the metropolitan area of Pamplona is incomplete, as despite achieving a high number of surveys; the low percentage of cyclists back then, did not provide sufficient information to avoid considering specific studies. Even so, by extracting the answers that are solely related to cyclists, you can use them as a specific survey for this group of citizens, and their data would therefore be similar to that from the previously mentioned studies and above all, its validity lies in its special contribution to the attractor destinations when planning and managing.

Bicycle counts

The third largest type of study developed in Pamplona was bicycle counts (Fig. 1).

The first one was developed in 2015, in parallel to the survey work carried out by the City Council of Pamplona. It was done manually, in just one working day and simultaneously in 14 sampling points throughout the city. The counters worked for 14 hours (between 7:30 and 9:30 p.m.) and recorded a total of around 20,000 bicycles passing.

The next bicycle count was carried out in 2016, taking reference to the previous one and with the aim of complementing it. While some counting points were repeated, others were new.

There was a total of 10 counting points, using the automatic measuring method with rubber tubes, and therefore, measurements could be taken 24 hours a day, for several days.

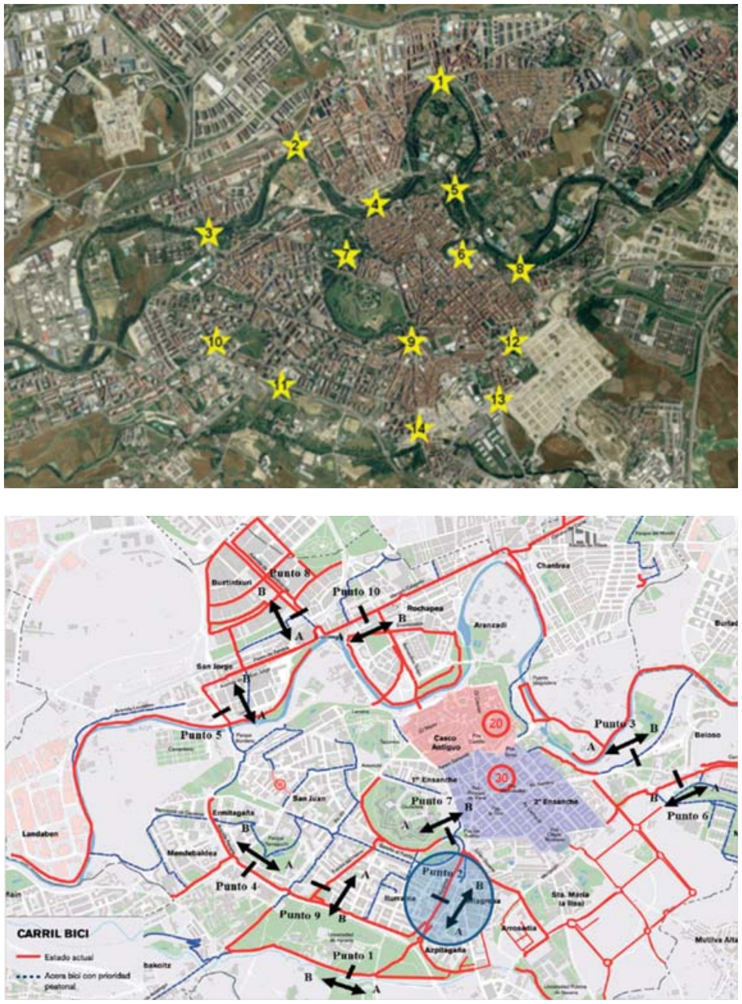


Figure 1. The bicycle count points in the City Council of Pamplona in 2015 (left) and the Pamplona District Mancomunidad Association in 2016 (right).

In addition to these counts, other activities of a more specific nature and with more specific objectives were developed,

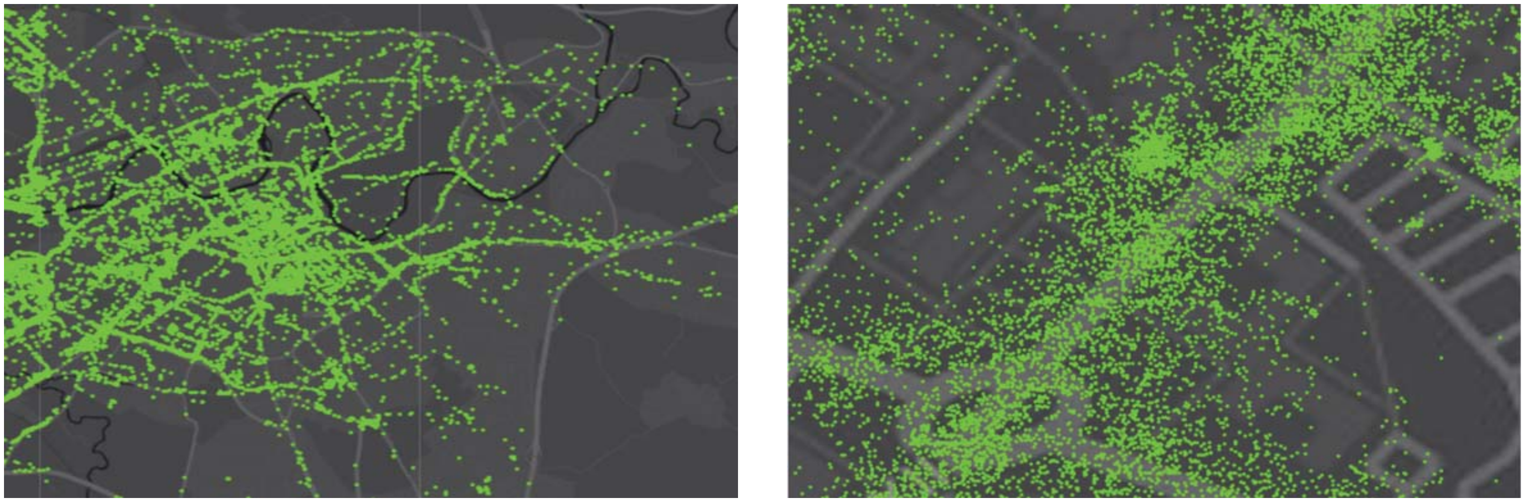


Figure 2. Cycling mobility corridors recorded by the volunteers of the LIFE+RESPIRA project.

Between 2013 and 2015 Jesus Sukuntza, member of a healthy sustainable mobility association, (AMTS), carried out a long-term bicycle count at a fixed point at the Vuelta del Castillo with an hour's measurement per week. The aim was to measure the changes in the flow of cyclists due to trends, seasonal changes, and meteorological phenomena, etc.

More recently (at the end of 2017), Jesus Sukuntza himself promoted and coordinated a group of volunteers who counted in 6 points within the first extended area of Pamplona with the aim of analysing the cyclists' preferred movements in terms of the type of road on which they ride. The study counted passing bicycles for 2 hours over the course of 3 working days.

Finally, it is worth mentioning another type of bicycle count, which differs to the previous ones, whereby parked bicycles are counted as opposed to moving bicycles. They have been carried out for years by Professor Arturo Ariño, from the Faculty of Sciences of the University of Navarre, which rely on the collaboration of interns studying Ecology.

Work like this, which focuses on manually counting the number of passing bicycles at certain count points located on bicycle lanes, and measuring the occupancy of parked bicycles, has the potential to be repeated in similar conditions for years, so the findings that can be obtained are of interest for longitudinal studies on the use of bicycles in Pamplona.

Geolocation-based Tools

The latest type of study developed in Pamplona are those based on ICT tools, which allow for a geographic positioning, and, therefore, mapping of the cyclists' routes.

Both experiences that we are aware of, were developed linked to the LIFE+RESPIRA project itself.

The sensors that were used by the projects' volunteer cyclists to record the air pollution values simultaneously showed their location in main streets of the city as they moved about. As can be seen in Figure 2, the millions of points recorded clearly illustrates the most important transport corridors, and, what is even more interesting is that it shows the location of the type of street in which the bicycles commute.

The second experience has to do with the LIFE+RESPIRA educational program and the work that was carried out with 10 educational centres to trace the routes the students take to go to school. In this case, the Wikiloc application was used and by filtering students who commuted by bicycle, we can obtain a fairly detailed map of their urban routes, albeit not that dense, due to the low use of this mean of transport.

Conclusions

Bicycles have gone unnoticed in the urban mobility studies developed in Pamplona until very recently. There were hardly any studies focused on this mode of transport and those of a more general nature were not taken into account. However, over the last five years there has been a growing concentration of works with different features (surveys, bicycle counts, etc.) which have allowed for great progress to be made in better understanding this phenomenon.

This spark of interest in bicycle mobility (which was paralleled by the increasing importance of bicycles in the combined urban mobility in the city), has not always stemmed from public entities responsible for mobility panning and management, but rather from civil society and the university sector (at least in an initial stage).

As of today, there are many parallel works that in some cases overlap in time, but they have the disadvantage of not covering the whole range of desired aspects of mobility, nor are they methodologically comparable with each other.

Rather than repeating the studies, a greater complementarity must be found between the works carried out by public institutions and private entities so as to lay the foundations for a comprehensive system to characterise bicycle mobility in Pamplona.

References

Ayuntamiento de Pamplona, 2005a. Pacto local de movilidad sostenible de Pamplona. Aprobado en sesión del día 30 de noviembre de 2005. Url https://www.mcp.es/sites/default/files/basicpage/pacto_movilidad_pamplona.pdf [consultado 12/12/2017].

Ayuntamiento de Pamplona, 2005b. Plan de ciclabilidad de Pamplona. Documento de trabajo inédito.

Gobierno de Navarra, 1997. Movilidad en Relación con el Transporte Urbano en la Comarca de Pamplona. Memoria Síntesis. Departamento de Obras Públicas y Transportes. Servicio de Transporte. Documento de trabajo inédito.

Gobierno de Navarra, 2006. Movilidad en relación con el transporte urbano en la Comarca de Pamplona 2006. Documento de trabajo inédito.

Gobierno de Navarra, 2007. Observatorio de la movilidad y del transporte de la Comarca de Pamplona. Pamplona: Gobierno de Navarra, Departamento de Obras Públicas, Transportes y Comunicaciones. Dirección General de Transportes.

Gobierno de Navarra, 2008. Plan de movilidad urbana sostenible de la Comarca de Pamplona. Documento de trabajo inédito.

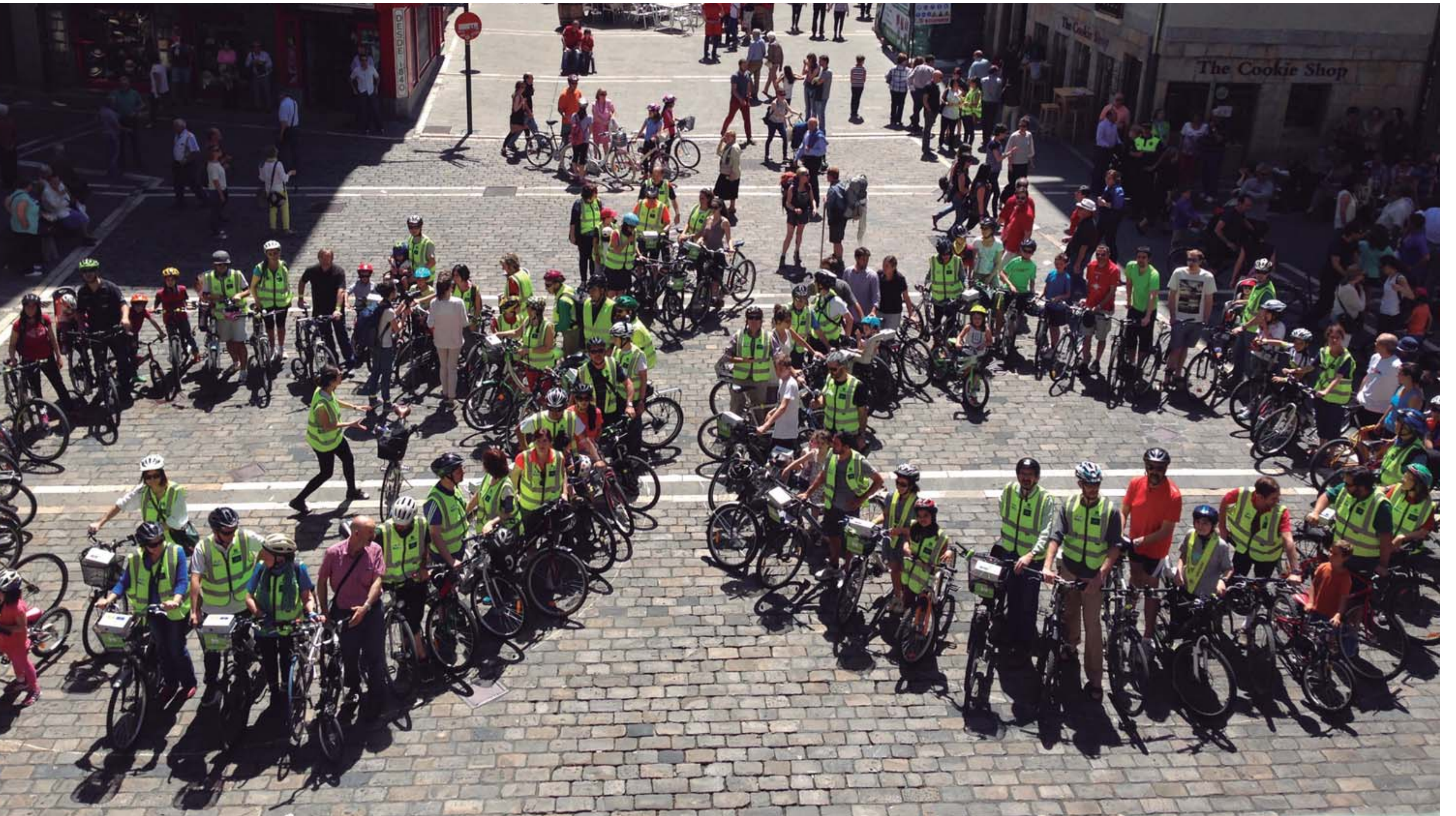
Mancomunidad de la Comarca de Pamplona, 2014. Análisis y Diagnóstico de la Movilidad en la Comarca de Pamplona. Documento de trabajo inédito.

Nosal, T. y Miranda-Moreno, L.F., 2014. The effect of weather on the use of North American bicycle facilities: A multi-city analysis using automatic counts. Transportation Research Part A 66: 213–225.

Pazos, M., 2005. El estudio de la movilidad diaria en España: limitaciones en las fuentes y alternativas propuestas. Ería, 66 (2005), págs. 85-92.

Zangenehpour, S., Miranda-Moreno, L.F. y Saunier N., 2015. Automated classification based on video data at intersections

7. ENVIRONMENTAL COMMUNICATIONS AND EDUCATION



LIFE+RESPIRA: a cross-media communications campaign

The Internet offers ample opportunities to spread the word through different formats and narrative methods. It takes away some of the limitations associated with traditional media, which place significant restrictions on portraying an accurate and effective representation of the environment (León, 2007).

The quality of the representation of environmental issues carried out by traditional media has faced a lot of criticism, including one of not being able to inform the public effectively or to engage citizens in the cultural shift that the planet demands. Against this background, the digital environment offers a more promising outlook as it allows the use of a wider range of media and storytelling forms, thus making it possible to show a more flexible representation (León, 2015).

In this process of involving the public, the role of scientific institutions that work in various aspects of environmental matters have now become relevant to an unwonted degree. Now research centres, citizens' associations and environmental groups have new tools to better engage the public.

Cross media communication

The actors of these new environmental communicative processes are well aware that it is no longer a question of producing content for a single means of dissemination, but rather to come up with transmedia strategies, which yield the best possible results of content designed for multi-channels.

Indeed, in the digital world, every media outlet is no longer limited to disseminating content with just one type of medium (images on television, sounds on the radio, etc.), but rather opting, to a greater or lesser extent, to spread content through various formats, for example, all of them disseminate texts, photos and videos on their social networks.

Thus, communication models arise, based on cross media strategies where they utilise content that is distributed through multiple channels, using various media and formats, such as texts, images, videos and audios (Veglis, 2014). These contents are frequently designed following a joint strategy and are disseminated co-ordinately across the different platforms.

As is well known, the Internet has evolved into Web 2.0, in which participation is becoming a fundamental component, to the extent that it has radically changed the conventional producer-consumer model, opening the gate to what are known as “Prosumers”, who, as well as consuming content, also become an integrated part of the production process (Toffler, 1980). Thanks to the tools that make it possible, that long-held, legitimate aspiration of how to get public feedback is now more feasible than ever.

The vertical and two-way models are giving way to another, in which horizontal interactions prevail. This makes it possible for a virtual community to emerge, whereby a complex network of relations is established between citizens and institutions with common interests.

The internet plays a key role in the communication of the environment, due to the ease of convergence with other media, the few constraints between the public and the private and its intrinsic orientation to individual users (Adams and Gynnild, 2013: 114). Moreover, this new paradigm is especially suitable for developing environmental volunteering projects, because in this area “being visible is a prerequisite in getting more widespread social recognition, facilitating volunteer involvement and obtaining resources” (De Castro, 2002: 330). In this light, social networks establish themselves to be instruments of great potential, as they facilitate contact between project managers and environmental volunteers, opening up vast opportunities to communicate, grounded on proximity and feedback (Adams and Gynnild, 2013: 116).

LIFE+RESPIRA'S communication plan

As articulated previously, LIFE+RESPIRA was designed in a way that the citizens were key actors in the research, whilst also being the direct beneficiaries of the results. The characteristics, nature and way in which the research was carried out made communication one of the key elements of this project, since it proved crucial in educating and informing the various target audiences. As a result, an ambitious cross-media plan was implemented, which included over one hundred actions over three years of research, conducted by a cross-functional team made up of environmental-communication, advertising, marketing, social-network, and audio-visual production specialists.

In line with the project's overall approach, the communication plan seeks to educate and sensitize on the importance of air quality, disseminating the results obtained from the research, as well as raising awareness of the convenience of using bicycles as a means of urban transport as an ideal tool for improving air quality.

Table 1. Communication actions by target audience.

Target audience	Scientific community	Project volunteers	Groups who are concerned about the environment	Public institutions and administrations	The Public
Actions	Scientific publications Communications to conferences International seminars Proceedings of the international seminar Twitter profile Corporate brochure (in Spanish, Basque and English) Information boards	Face-to-face training and motivation sessions Information boards Flyers Press conferences Press releases Email address Newsletter Website Facebook profile Twitter profile YouTube channel Documentary in Spanish and English Videos in Spanish and Basque Radio shows	Presentation workshop for the project Technical workshop for the project Technical paper Newsletter Website Twitter profile Facebook profile YouTube channel Teaching unit about the quality of air, mobility and health. Videos Documentary Radio shows Information boards Flyers in Spanish, Basque and English Posters Merchandising material such as: T-shirts, bicycle accessories, rucksacks etc.	Awareness session	Website in Spanish, Basque, English and French. Presentations and workshops related to special dates and occasions Press conferences Press releases Video releases Handling media relations Documentary (Spanish and English) Videos (Spanish and Basque) Twitter profile Facebook profile YouTube channel Contest for the creation of the logo Photography competition Layman's report


Figure 2. The human bicycle in the Town Hall Square of Pamplona. Photo by Manuel Castells.

There were 5 different target audiences in the communication campaign:

1.The scientific community: an interdisciplinary group made up of more than 32 researchers and specialists from a variety of disciplines involved in the project: Environmental Chemistry, Mobility, Ecology, Bioinformatics, and Environmental Communications.

2. The Project volunteers: 121 men and 79 women between the ages of 18 and 71 whose involvement was one of the core elements in carrying out the investigation.

3. Citizens with a great deal of interest in environmental issues: people who are highly aware of and fully engaged and committed to environmental issues, including regular cyclists, as well as members of environmental groups and associations.

Figure 1. Brochure used in the Volunteer Recruitment Campaign, designed by Juan Boronat (Ojo de Pez Comunicación).

4. public institutions and administrations: key actors in urban air quality and mobility management.

5. The public at large: target audience through social media and other activities.

There were a variety of communication actions aimed at the volunteers (Table 1). We organised face-to-face events, information boards, brochures and printed material, press releases, videos posted on YouTube, radio programmes on the local 98.3 station and the University of Navarra, information posted on the project's own website, and stories and posts on Facebook and Twitter. We also maintained ongoing contact via email between the research team and the volunteers.

The communications addressed to the scientific community were shared at over 20 congresses held in various countries. The final closing seminar, held in Pamplona on 12th and 13th December 2017, proved useful as a framework to present the main results of the research.

As for the volunteer-targeted communications, the first few months of the project saw a particular focus on recruitment and attracting attention. Of note among the communication material used was a video (https://www.youtube.com/watch?v=vV--l1135KA) that was posted and broadcast on the YouTube channel and on the project's social network pages, a flyer (Fig 1.) and panels with similar information to the flyers that were attached to the bikes located in different parts of the city. This campaign enabled us to reach the total amount of 150 volunteers in the first eight months of the project, which exceeded the initial estimates.

Once the group was created, we maintained continuous communication and follow-up with the volunteers via phone calls and emails with the aim of consolidating the group and encouraging involvement in the project. We also held face-to-face meetings and events, such as a bicycle march through the city, ending up in the Town Hall Square of Pamplona, where the volunteers gathered to form the shape of a large bicycle (Fig. 2).

The communication aimed at the environmentally-conscious community was primarily channelled through the website and social networks. The website: (www.liferespira.eu), which was available in Spanish, Basque, English and French gained more than 16,000 users and received over 43,000 hits in December 2017 (Fig. 3).

There was active participation in the social networks sites throughout the whole project. Our Facebook profile received 1500 likes and the Twitter profile reached over

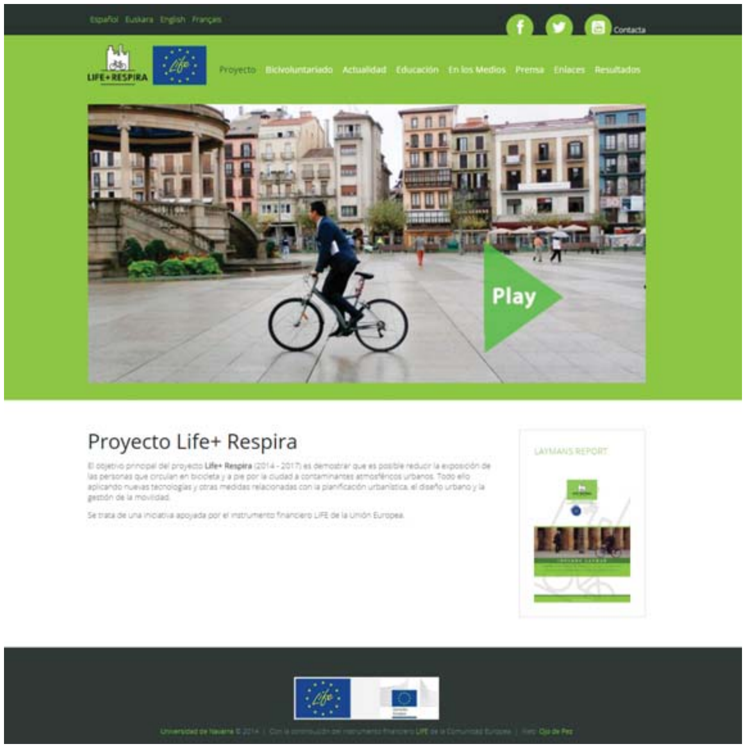


Figure 3. The project's website, designed by Juan Boronat (Ojo de Pez Comunicación).

860 followers by 31st December 2017. Some noteworthy pieces of material produced in-house and relayed through social networks were 20 1-5-minute videos posted on YouTube, which between them reached a total of 6,700 views. We also created a document about the research project, which was shown in specialised seminars and distribution platforms on the Internet.

The communications that were aimed at the public institutes consisted of numerous meetings with public entities, such as the City Council of Pamplona and the Pamplona District Mancomunidad Association, where the project was disseminated and promoting various forms of collaboration.

Lastly, LIFE+RESPIRA tried to reach out to the public at large, primarily through mainstream media. To disseminate the project's process and results, we called eight press conferences and released 15 press releases. The project was covered by more than 130 local and national media outlets (press, radio, television and digital media) with an estimated global audience of over 10 million people. Some noteworthy material about LIFE+RESPIRA published by the national media include: online editions by the EL País and La Vanguardia newspapers (Fig. 4), as well as the news on channels Tele 5 and La Cadena Ser.

Figure 4. Publications in the national press.

References

Adams, P. C. y Gynnild A.. (2013): Environmental Messages in Online Media: The Role of Place. Environmental Communication. Vol. 7, No 1, pp. 113-130.

De Castro, R. (2002). "Voluntariado, altruismo y participación activa en la conservación del medio ambiente". Intervención Psicosocial, Vol. 11 N.° 3, pp.: 317-331.

León, B. (2015). "El medio ambiente y sus imágenes. Hacia un nuevo modelo de representación", en León, B. (coord.), El medio ambiente en el nuevo universo audiovisual. Barcelona, UOC, pp. 17-34.

León, B. (2007). "El medio ambiente en las televisiones españolas. Un análisis de contenido de los informativos nacionales", en Contreras, Fernando, et al., Cultura verde: Ecología, Cultura y Comunicación. Sevilla, Junta de Andalucía, 2007, pp.: 361-373.

Toffer, A. (1980). The Third Wave. New York, Bantam Books.

Veglis, A. (2012). "From Cross Media to Transmedia Reporting in Newspaper Articles". New York, Springer Science and Business Media.

Education programme on the quality of air and sustainable mobility

Childhood and mobility

Mobility is one of the main factors that determine the characteristics of a city: the landscapes, noise, air quality, commerce or even the relationships that develop between citizens. Thinking about the type of mobility model we want is like asking ourselves which style of city we choose to live in and pass down to our children.

Motorised transport is the part of the urban system that most conditions the morphology of the city. The layout of neighbourhoods and local urban settings, such as the spaces surrounding education centres depend largely on the organisation of motorised traffic. It makes sense then that a lot of the changes in social behaviour which undermine the quality of communal areas and the development of coexistence stem from motorisation. In a study carried out in the streets of San Francisco in the seventies (Appleyard and Lintellen,1972), they found that there was a proportionately inverse relationship between the levels and intensity of traffic in the streets and the quality of neighbourly relations. The authors examined the harm that busy roads in neighbourhoods cause and found that the higher the speed and number of vehicles on the roads, the fewer the social contacts people had in those areas.

Children are particularly hard hit by the effects of urban transformation caused by motorised transport. They miss out on playing in the streets, getting about independently, including themselves in society and contributing to family life.

As far as children's health is concerned, we know that allergies, particularly respiratory problems are the direct result of air pollution. According to the WHO (in 2017), every year 570,000 children under the age of 5 die from respiratory problems, such as pneumonia, attributable to air pollution, and second-hand smoke. Furthermore, research in neurological health confirms that it also inhibits their cognitive development (Mortamais et al., 2017).

Besides poor air quality, other factors that are associated with urban transformations, such as noise pollution or not having direct visual contact with natural materials (trees, plants, earth...) contribute to stress and inattentiveness (Kahn y Kellert, 2002; Dadvand, et al., 2015; Sunyer et al., 2015).

On the other hand, commuting by foot, bicycle or other active means of transport is a great opportunity to promote physical activity for the general public, especially for children and the younger generation. Almost half of the children and young people in Spain didn't meet the recommendations with regards to physical activity (FIN, 2016). Getting exercise by walking and cycling to school prevents obesity problems and is also reflected in school children's concentration levels.

The future of our cities depends on children and their education. The reference by Italian sociologist and pedagogue, Francesco Tonucci and his work: "The Children's city" (1996) are well known. In this project, he proposes a broad-based rethinking of the city, whereby children's perspectives are taken into account, letting them have a say in their future.

In the wake of all these approaches, guides and other accompanying technical documents have been developed, which aim to facilitate and boost the development of mobility-related experiences in children and young people in cities (Schollaert, 2002, Román and Salís, 2010, Román, 2013).

There are many education centres or municipalities themselves that are aware of this, and are working to promote sustainable daily commuting to school (Fig. 1), either with the roll-out of school routes or with other initiatives (Sustainable Mobility Plans to education centres, etc.).

The LIFE+RESPIRA educational program

The school community is ideal for replicating this initiative, setting standards in the quality of air and mobility, having a significant multiplier effect on their families and on society as a whole. On the basis of this, environmental education was the cornerstone in the LIFE+RESPIRA project.

With the twofold objective of sensitizing young people about the importance of the quality of air in cities, (together with its related factors, such as management policies, urban model planning etc.), and adopting sustainable and healthy mobility habits, LIFE+RESPIRA developed an educational project called RESPIRA: "Fresh Air For An Educational, Health And Safe City" (Fig. 2), which was offered during the academic year 2016-17 to compulsory secondary-education and third-grade primary school students who live in Pamplona and the surrounding region.

Figure 1. Initiatives to promote sustainable mobility

Figure 2. A teaching guide of the LIFE+RESPIRA didactic project and the Mancoeduca website where the RESPIRA workshop was offered.

It is important to note that the mentioned educational programme was backed by the Department of Education of the Navarre Government and the City of Navarre's school committee. We also benefited from the collaboration of Mancoeduca, a renowned environmental educational programme, created 25 years ago by the Pamplona District Mancomunidad Association (MCP), a local institution in charge of public transport.

The didactic project contains a set of goals that are listed below:

- Acquiring knowledge about air quality, the urban determining factors that are related to it, and how health is connected.
- Acquiring scientific, technological, social and communicative skills and competencies which are linked to the development of the didactic sequence in which various elements and materials interconnect.
- Fostering their creative and imaginative skills to be able to tackle and resolve the urban environmental issues so that they can implement it in the school's immediate surroundings.
- Adopting citizenship skills both for now and for the future, as it paves the way for children and young people to participate in the process of environmental improvements of the city.

The educational program includes the following activities:

1. Training sessions for secondary school teachers and Mancoeduca staff, in which teachers are taught by researchers from LIFE+RESPIRA on air quality and sustainable mobility know-how.

2. Research and awareness-raising talks and workshops, whereby the students themselves think about the urban surrounding of their schools under the supervision of an expert in environmental education or one of our LIFE+RESPIRA researchers. These one-hour talks were held in the classrooms at their educational centres and were given by the project's researchers and staff from Mancoeduca that had been specially trained on the matter. Each workshop was divided into the following main parts:

a) Analysis of the students' mobility habits and their implications at different levels (city, landscape, health, etc.).

b) A walk along the pedestrian routes in the immediate surroundings of the school with analysers from the LIFE+RESPIRA project, to collect data on pollution.

c) Characterization of the urban environment around the educational centre: identifying problems and coming up with proposals.

d) Analysis of the information (Fig. 4) collected from the sensor using a range of material (maps, orthophotos etc.)

e) The search for creative and practical solutions, which could be of a different nature, given that the subject can be approached from diverse disciplines, and/or using a variety of techniques (Fig. 5). This phase was only carried out in some educational centres, where they voluntarily agreed to develop a research project linked to LIFE+RESPIRA. The students involved worked like actual researchers.

Figure 3. The walk taken by secondary students along the pedestrian route in the immediate surroundings of their education centre.

Figure 4. Reflecting on urban environmental problems is an essential part of the learning process.

Figure 5. The proposals are highly diverse and require a great deal of imagination and creativity.

Figure 6. On-line surveys carried out on both students and their families.

Figure 7. Teachers receiving the training.

3. Surveys. Surveys on mobility (Fig. 6) were conducted online by schoolchildren and their families, which questioned - among other things - their view on the journey that the students take in their daily commute from their homes to school. The education centres that participated provided real-time information of the results of the survey using Google Drive as access. This privileged information will allow them to design an ad hoc solution for each case.

4. Analysis of journeys. The students identified the routes they took in their commutes to school using various digital platforms, which enabled them to develop what we call a “commuting web”, which is nothing more than the joint mapping of each of the routes taken by the students.

5. Activities with the school’s parents’ association. A creative urban workshop aimed at families was offered to the school’s parents’ association, which was held at The Navarre University Museum, followed by the possibility of visiting the museum’s collection of exhibitions and the building.

Main results

More than 2,000 students between the ages of 10 and 16, belonging to 31 different education centres in Pamplona and its surrounding region participated in **talks** and **workshops** assigned to the LIFE+RESPIRA educational project. The 94 activities were given by either the staff at Mancoeduca, (7 educators and technicians were specially trained by LIFE+RESPIRA’s researchers for this purpose) (Fig. 7) or by the LIFE+RESPIRA scientists themselves (apart from the activities held at The Navarre University Museum).

Of the total students, around 800 from 10 different centres received more thorough training and even developed particular school projects based on workshops led by their own teachers (16 in total), which were specially trained beforehand by LIFE+RESPIRA staff. During these school projects, they came up with proposals to increase safety and convenience for pedestrians and cyclists, improve the signposting and design of public areas, ways to limit their journeys using private vehicles, and to redesign and beautify urban street furniture (Fig. 8).

The educational programme designed and implemented by LIFE+RESPIRA was extremely well received by the teachers involved, because they regard proximity as a factor that truly impacts students. This very high level of satisfaction among participating schools ensures, in part, the future continuity of the programme once the LIFE+RESPIRA project has completed.

The proposals were followed through to a greater or lesser degree, depending on the particular efforts made by each centre.

The work and proposals made by the 10 educational centres that were most involved were later presented at a conference that was held at the Navarre School Committee's headquarters before the completion of the

Figure 8. An air quality measuring station belonging to a network of control stations owned by the Navarra Government being beautified by high school student's own designs. By doing this, it showed the locals what it is used for, whilst also promoting responsibility in the students.

Figure 9. A forum of participation of schoolchildren, accompanied by their teachers and researchers from the LIFE+RESPIRA project together with public entities. The students share their reflexions and proposals to the competent authorities. Source (left image): http://www.navarrainformacion.es/2017/06/18, (right image): https://pamplonaactual.com/alcalde-pamplona-recibe-las-sugerencias-los-escolares-mejorar-la-calidad-del-aire-la-capital/

INDICATORS FROM THE LIFE+RESPIRA EDUCATIONAL PROGRAMME

31	educational centres in Pamplona and its surrounding region participated in the activities of the educational project.
16	teachers were specially trained and participated in the project by directing it to the students.
2014	students participated in the educational projects' activities.
10	education centres directly participated in the project, developing a school project.
800	student researchers participated in the educational project.
7	Mancoeduca educators and technicians were specially trained.
4	activities for the school's parents' association. (3 workshops in the Navarre University Museum and 1 meeting.
94	training events developed (involving the 2014 students).
2500	surveys conducted by students and 600 by parents.

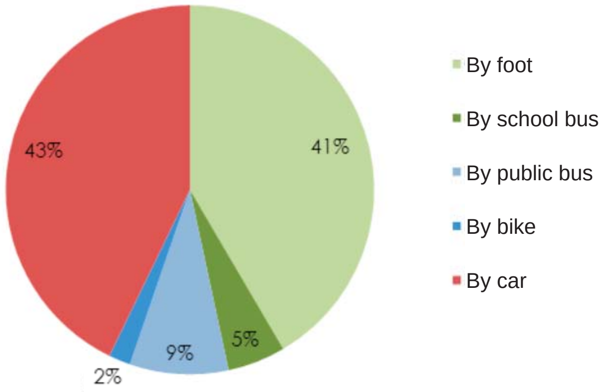


Figure 10. Modal split of transport that the students of Pamplona and the its surrounding region use in their commutes from home to their education centres.

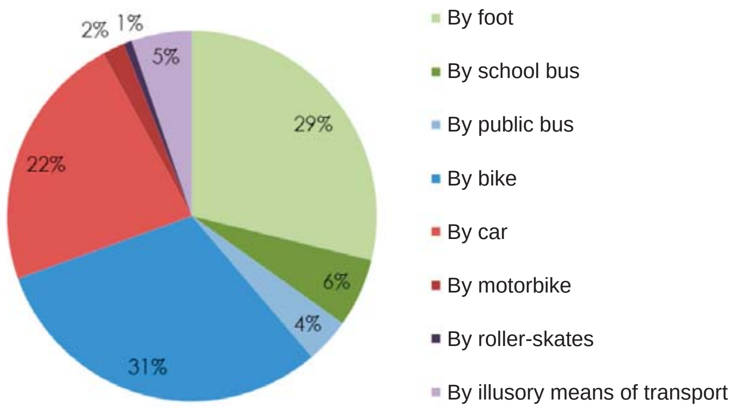


Figure 11. Modal split of journeys that the student wished to use in their commutes from home to school.

LIFE+RESPIRA project. During this meeting, the students had the chance to showcase their ideas and findings to the highest authorities of the City Council of Pamplona and Villava, the Pamplona District Mancomunidad Association and the School Committee, as well as The Directorate-General for Education and Environment of the Navarra Government.

The students, who were accompanied by their teachers (Fig. 9), publically presented their proposals that they had developed in their schools as part of the education programme, and handed the Mayor a dossier with all the gathered information from their projects.

Below are the main results of the school mobility survey: Survey 1 was completed by 2,500 schoolchildren between the ages of 6 and 16 and over 600 families, belonging to 10 education centres.

The survey found that the percentage of students that commuted to school by car equalled that of those who used non-motorised means of transport (41% by foot and 2% by bike, with the remaining 14% who commute by bus). It should be noted that the modal split of journeys taken by the students in their commutes to school is one of the common European voluntary indicators included by the European Commission in the “Towards a Local Sustainability Profile” proposal, (a Working Group, who measure, follow up, and evaluate local sustainability, a group of experts in Urban Environment, 2000), whose objective is to support local authorities by providing comparable and objective information on the progress made in the area of sustainability in Europe as a whole.

Based on the responses received, if it were up to them, 31% of the students would go to school by bicycle (a percentage that is far surpassed by other studies (Dekoster and Schollaert, 2000)), and 30% would opt to go by foot. If their desires were to be fulfilled, the number of pedestrians would fall, giving way to more cyclists.

What is interesting to highlight is that there were disparities in the students’ preferences, depending on whether they were in primary school or high school. The appeal of going by bike declined with age, dropping from 42% to 28%, although commuting by foot increased (from 24% to 34%), without offsetting the difference. However, it is also apparent that less than a quarter of the student s wished to commute to school by car (Fig. 11).

SCHOOL CHILDREN who commute by car; why don't you go by foot or by bicycle?

Figure 12. School children commuting to school by bicycle.

The reasons the students gave for commuting by car instead of using active means of transport varied greatly (Fig. 12). These are the most common (in order): distance, weather conditions, and carrying weight. These three reasons make up half of the responses. Some other reasons mentioned were down to infrastructure (no bike lanes, having to go up hills, not having anywhere to park their bikes at school, or they thought it was unsafe, etc.) and others, such as ‘my parents do not let me’, ‘it scares me’, ‘I do not like walking or cycling’ etc.).

There are practically only three reasons given by parents for taking their children to school by car (which make up 95% of the responses). In the following order: ‘I make the most of my commute to work by dropping off my children by car’, ‘we live too far away from school’, ‘it’s the most convenient way’.

When it came to their views on air quality, one out of every 2 students said that they had experienced air pollution on their way from home to school. Although the difference is small, those who cycle were more sensitive in this regard. This data could be surprising for a city like Pamplona, which is, a priori, not especially “polluted”. This is explained by the influence of the educational project itself, since if we compare the students’ responses with those of their parents who were not trained on the issue (around one out of every three), there were substantial differences. Furthermore, this data is also in line with the results of the Opinion Poll on pollution carried out by LIFE+RESPIRA.

Moving on to another activity, the analysis of students' commutes provided a detailed picture of the most frequented streets and squares by the school children in the participating schools who walk or cycle (Fig. 13).

If required, this information allows for detailed project work to be done on road safety, school routes, beautification of the immediate surroundings of the education centres, etc. This information generated as part of LIFE+RESPIRA can be of use to other future projects, driven by the schools themselves, or by Public Administrations.

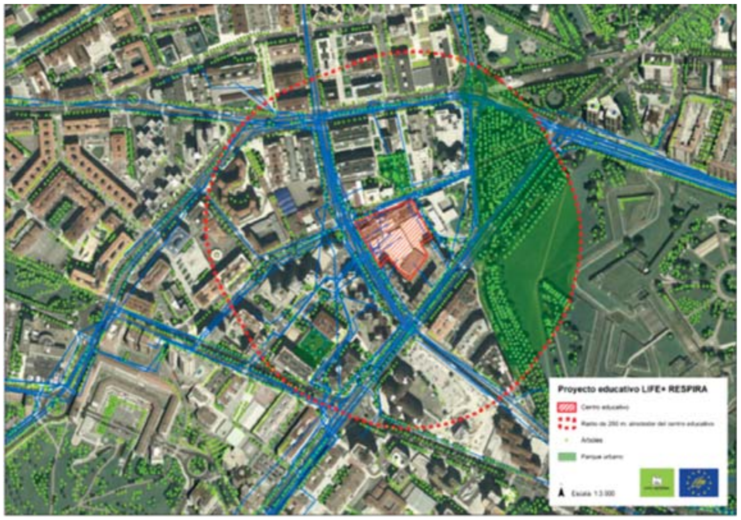


Figure 13. Routes taken by students walking or cycling from their houses to school.

Figure 14. Parents and children during the creative workshop given at The Navarre University Museum.

Regarding the activities with the school's parents' association, a talk was given by members of the Mancoeduca staff in the education centres. In addition to the activities carried out in schools, four workshops

aimed at families were held in The Navarre University Museum under the framework of the educational project (Fig. 14). They served to raise awareness among both adults and children in a creative and artistic context on the environmental impacts caused by our mobility choices.

Conclusions

Childhood is a crucial time for adopting and consolidating good habits that can be reverted back into the city. This educational initiative has helped to raise awareness and sensitize children and young people about the importance of air quality and adopting healthy and sustainable lifestyle habits so as to improve the quality of life of their cities, where they can play an active role. Not only did they act as the drivers of change in sustainability-related issues in their schools, but they also took part as active citizens, sharing their views and proposals to the competent authorities.

RESPIRA: "Fresh Air For An Educational, Health And Safe City" is an innovative proposal which allowed children and young people, as well as educational communities to get involved in the LIFE+RESPIRA project, to drive forward information, and training and encourage the adoption of healthy and sustainable mobility habits that contribute towards urban transformation.

It is an integrated didactic project (1), as it promotes interaction among the education centres and also between them and the project's researchers and the volunteers, encouraging involvement and the experimentation of the benefits of the collaborative work and networking; and flexible (2), since centres concerned were able to approach the research from varying perspectives and adjust the temporal sequence according to their programme interests. The centres boosted changes in infrastructures and habits using a more scientific, creative, or more participatory approach. The obtained results may also serve to support other related projects, such as safe school routes, or sustainable mobility plans for school commutes.

The integration of the LIFE+RESPIRA educational project in Mancoeduca allowed part of the educational activities to continue beyond the precise duration of the project. A milestone for the LIFE project was when The Pamplona District Mancomunidad Association offered to extend the LIFE+RESPIRA workshop for this and probably other future academic years. This collaboration also enabled strengthening of relationships between institutions and the transport authorities of the Pamplona metropolitan area, which will help to implement our educational project.

SUGGESTED IMPROVEMENTS

Development of school route projects that inspire and engage families, teachers, Public Administrations and other actors involved.

Development of sustainable mobility plans for education centres in line with the implementation of sustainable mobility policies.

Promotion of versatile didactic projects. Due to their cross-sectional nature, air quality and sustainable mobility are topics that can be addressed in different subjects at school, (Physics, Chemistry, Citizenship, Ethics, Social Sciences, Biology, etc.). The school management and faculty have the opportunity to approach the didactic project from the perspective that best suits their circumstances.

To guarantee the continuity of didactic projects that are performed in a LIFE research context, or of another nature, seeking collaboration with a platform such as The Pamplona District Mancomunidad Association (in this case) is highly recommended, guaranteeing its continued implementation.

References

Appleyard D.; Lintell M., 1972. The Environmental Quality of City Streets: The Residents' Viewpoint. Journal of the American Institute of Planners 38 (2): 69-83.

Dadvand P., Nieuwenhuijsen M.J., Esnaola M., Fornsa J., Basagaña X., Alvarez-Pedrerol M., Rivasa I., López-Vicente M., De Castro Pascual M., Su J., Jerrettg M., Querole X., Sunyer J., 2015. Green spaces and cognitive development in primary schoolchildren. Proceedings of the National Academy of Sciences 112 (26): 7937-7942.

Dekoster, J., Schollaert U., 2000. Cycling: The Way Ahead for Towns and Cities. EDC collection. Office for Official Publications of the European Commission. ISBN 9789282880982.

FIN, Fundación para la Investigación Nutricional, 2016. Informe 2016: Actividad Física en niños y adolescentes en España. Descargable en:
https://www.activehealthykids.org/wp-content/uploads/2016/11/spain-report-card-long-form-2016.pdf. [Consulta 10/01/2018].

Grupo de trabajo de medición, seguimiento y evaluación de la sostenibilidad local, grupo de expertos en medio ambiente urbano, 2000. Informe técnico: Hacia un perfil de la sostenibilidad local. Indicadores comunes europeos. Dirección General de Medio Ambiente. Oficina de Publicaciones Oficiales de las Comunidades Europeas, Luxemburgo.
ISBN 92-828-9414-2.

Kahn P.H., Kellert S.R., 2002. Children and Nature: Psychological, Sociocultural, and Evolutionary Investigations. MIT Press, Cambridge, MA.

Mortamais M, Pujol J, van Drooge BL, Macià D., Martínez-Vilavella G., Reynes C., Sabatier R., Rivas I., Grimalt J., Forns J., Alvarez-Pedrerol M., Querol X., Sunyer J. 2017. Effect of exposure to polycyclic aromatic hydrocarbons on basal ganglia and attention-deficit hyperactivity disorder symptoms in primary school children. Environ Int., 105: 12-19.

OMS, Organización Mundial de la Salud, 2017. Don't pollute my future! The impact of the environment on children's health. Ginebra (Suiza). CC BY-NC-SA 3.0 IGO.

Román, M. 2013. Camino Escolar Paso a Paso. DGT, Dirección General de Tráfico. Descargable en:
http://www.dgt.es/es/seguridad-vial/educacion-vial/recursos-didacticos/infancia/proyectos-de-camino-escolar.shtml, Consulta [10/01/2018].

Román M.; Salís I., 2010. Camino escolar. Pasos hacia la autonomía infantil. Ministerio de Fomento. Descargable en: http://www.fomento.gob.es/MFOM/LANG_CASTELLANO/_ESPECIALES/CAMINO_ESCOLAR/. Consulta: [11/01/2018].

Schollaert, U., 2002. La ciudad, los niños y la movilidad. Oficina de Publicaciones Oficiales de las Comunidades Europeas. Luxemburgo.

Sunyer J., Esnaola M., Alvarez-Pedrerol M., Forns J., Rivas I., López-Vicente M., Suades-González E., Foraster M., García-Esteban R., Basagaña X., Viana M., Cirach M., Moreno T., Alastuey A., Sebastian-Galles N., Nieuwenhuijsen M. y Querol Q., 2015. Association between Traffic-Related Air Pollution in Schools and Cognitive Development in Primary School Children: A Prospective Cohort Study. PLoS Med 12(3): e1001792. doi:10.1371/journal.pmed.1001792

Tonucci F., 1996. La città dei bambini: un modo nuovo di pensare la cittá. Laterza, Roma.

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