LIFE13 ENV/ES/000263

FINAL Report

Covering the project activities from 01/10/2014 to 31/03/2018

28/06/2018

IMPROVE LIFE

Implementing methodologies and practices to reduce air pollution of the subway environment

Project Data

Project location	Barcelona, SPAIN
Project start date:	01/10/2014
Project end date:	31/03/2018
Total Project duration (in months)	42 months
Total budget	813,727 €
Total eligible budget	813,727 €
EU contribution:	406,863 €
(%) of total costs	50%
(%) of eligible costs	50 %

Beneficiary Data (coordinator)

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2. EXECUTIVE SUMMARY

The overall aim of IMPROVE is to provide a benchmark study that will lead to real improvement in subway air quality. Millions of people worldwide commute to work using underground rail systems and many of these are routinely exposed to levels of contaminated air that are illegal above ground as well as being unusually metalliferous. Despite this, little realistic consideration has been given as to how subway air quality can be improved. The IMPROVE project has overviewed previous international studies, identified the main pollutant sources, and proposed cost-effective air pollution mitigation strategies. One of the core tasks was to work directly with public transport authorities, improving their awareness of air quality and encouraging their development of best practice policies designed to improve underground atmospheric conditions. Specific objectives included:

Objective	How was it achieved?
To determine the emission sources and their contribution to air quality in both platforms and trains, identifying those that have potentially higher health risk.	Creating the largest existing fully publicly available database on subway air quality. This database, unprecedented in scope and detail, includes comprehensive chemical analyses of rock ballast, catenary materials, electric brushes, and different types of pantographs, brake pads, rails and train wheels.
To evaluate the effect of air quality mitigation measures already used in some subway systems worldwide.	Carrying out air quality measurement campaigns in stations with different designs in both new and old lines, a minimum of twice, and at different times of the year, in order to compare changes in variables such as air conditioning and ventilation.
To develop and propose to local/national authorities effective air mitigation measures for subway systems.	Having face-to-face meetings with the authorities in various European countries presenting results on key points directly relevant to the problem of understanding air pollution underground, notably: - tunnel and rail track maintenance work activities; - applying different ventilation on protocols in tunnels, platforms and trains; - station designs and outdoor air infiltration; - contaminants released by the wear of train operational.
To assist local transport in the implementation of a Strategic Plan designed to reduce air contamination in subway systems.	Producing an innovative explanatory technical guide with recommendations on air pollution mitigation, distributed to transport authorities responsible for subway systems worldwide as well as related companies.
To encourage the use of effective air quality improvement measures by applying a communication strategy plan.	Disseminating the obtained results and suggested measures to improve the air quality in platforms and trains of subway systems, to stakeholders, media, with dissemination material and organising events.
To act as a catalyst for the allocation of local/national funds allowing implementation of air improvement strategies.	Implementing a vigorously proactive dissemination plan throughout the project (visits to 12 stakeholders, 5 TV interviews, 10 in radio programmes, 51 web releases, two videos,…) and in the after LIFE communication plan.

The problem addressed by IMPROVE

In the context of air quality, commuting by underground rail is one of the high-exposure periods among various daily activities, because inhalable airborne particulate matter (PM) levels in the subway environment are typically higher than those both above ground and in other indoor environments. Aerosol emissions specific to the subway include mechanical abrasion of rails, wheels, brakes and catenary, resuspension of material by air turbulence in the stations and tunnels, and PM emitted during night-time maintenance works.

As demonstrated in our reports, air quality on subway platforms shows a remarkably wide range of $PM_{2.5}$ concentrations from >100µg/m^3 to <25µg/m^3. The fact that some subways enjoy low $PM_{2.5}$ concentrations that approach the WHO guideline of 10µg/m^3 demonstrates that clean subway air is possible, and that commuters worldwide would benefit from a proactive attitude to improving air quality underground. A major focus of the project has therefore been to test measures to reduce PM concentrations in platforms and trains, taking into account variations in key factors such as station depth, date of construction, station design, type of ventilation, types of brakes used on the trains, train frequency and the presence or absence of platform screen door systems. The excellent working relationship between scientific researchers in CSIC and the engineers and managers of TMB has provided a unique opportunity for collaboration which, to our knowledge, has no equal worldwide.

Key deliverables and outputs of the IMPROVE LIFE project include:

- Identification and quantification of the impact of pollution sources in the subway system.
- A detailed chemical composition database for air quality on platforms.
- A website for the project activities (with the LIFE logo).
- Two informative videos in 3 languages -English, Spanish and Catalan- of 10 (in the web page) and 20 (to be shared with other subway systems) minutes.
- IMPROVE LIFE pamphlet.
- IMPROVE LIFE notice board.
- Sixty-six media and press releases (41 digital press, 10 newspapers, 15 radio and TV).
- A Layman's Report on Actions, Tools, Effects and Long Term Benefits from the project on both National and European level.
- Establishment of the scientific basis for effective policy-making through the peer-reviewed IMPROVE publication database (16 scientific publications, 18 presentations in conferences).
- Organisation of an expert's Workshop on "Commuter air quality in rail subway systems"
- Organisation of an international conference with transport authorities and policy makers.
- Organisation of an international LIFE platform meeting.
- Five reports on air quality in the subway environment available in the project web page.
- A technical guide with effective mitigation strategies distributed to subways worldwide.
- Three presentations to the Health Committee of Barcelona subway systems.
- Presentation of results in other Spanish (Malaga, Seville, Bilbao and Madrid) and European (London, Vienna) subways and to the prestigious International Association of Public Transports (UITP) following special invitation to a meeting in Rotterdam.
- Three Project Reports: Inception, midterm and final report.
- Publication of After-Life Communication plan.

Administrative part

The **project management team** was elected in the kick off meeting celebrated on the 28/10/2014. The Project Manager is T. Moreno (CSIC, Coordinating Beneficiary-CB), who along with key members of the CSIC research team was responsible for the implementation, progress and overall impact of the project. C. de Vasconcelos is responsible for Administrative and Financial management, as well as for compliance with the Grant Agreement. In addition, personnel from TMB-TB and TMB-FMB (Associated Beneficiaries-AB) assisted in the execution of the tasks during the work programme. Regarding organisational issues, the Grant Agreement was amended to have 3 partners instead of 2 (with no modification of the total budget already approved, or of the objectives, expected results, contents and aims of the project actions), due to TMB operating as two beneficiaries with separate VAT numbers. The request for this amendment of the Grant Agreement was submitted and subsequently approved on 20/01/2016 by the European Commission.

Main outcomes of IMPROVE

A **literature review** was conducted with the elaboration of 3 reports on: i) Historical PM levels and chemical composition database from studies conducted worldwide; ii) A literature review that discusses subway PM sources; iii) Main parameters relevant to subway air quality studies.

The Implementation Actions in IMPROVE LIFE (B1: Determination of the impact of selected parameters, and B2: Testing mitigation measures and development of mitigation strategies) provide scientific data on the problem. We have demonstrated how inhalable PM present in subway air is normally highest during peak transport hours and lowest at night when the trains stop running. However, a common exception is when night **track maintenance** work adds dust to the system, increasing inhalable $PM_{2.5}$ levels on the platform especially at the beginning of daytime train operations. In this context IMPROVE LIFE pioneered the application of a polymer-based dust suppressant to ballast rock fragments prior to the material being laid on the rail track. This resulted on a reduction of 20-50% in dust levels during ballast-laying and tamping, which translates to a lowering of early daytime platform $PM_{2.5}$ concentrations by at least 10%, although the effect was variable depending on distance between platform and work site, and timing of the work during the night. From a purely air quality perspective the use of rock ballast on the track would be better discouraged in favour of using concrete, although this is likely to generate noise issues. Another conclusion from our work was that the use of diesel engines underground should be phased out in favour of heavy duty electric vehicles, thus removing a significant source of night-time emissions.

IMPROVE LIFE has also demonstrated that the **type of ventilation system** operating in tunnels and platforms is a key controlling influence on subway air quality. Faster fan impulsion of outdoor air into the platform can produce much cleaner air by diluting ambient levels of subway particles, providing outdoor PM levels are not higher than those underground, whereas reversing ventilation air flow from impulsion to extraction damages platform air quality. Modern, powerful tunnel ventilation systems can result in excellent air quality but if they are switched off then platform $PM_{2.5}$ concentrations can more than double during train operating hours. During the IMPROVE campaigns an air purifier was demonstrated capable of reducing platform $PM_{2.5}$ concentrations by 30-38% when placed close to the measuring equipment. Thus air purifiers have the potential, but they need to be powerful and/or numerous to make a substantial difference worth the expenditure on equipment and energy.

Air quality **inside trains** in the Barcelona subway system is always better (30–50%) than on platforms when using air conditioning within a closed system that does not allow open windows. The air conditioning produces a notable improvement on both concentration and variability of PMx inside the trains, especially for the coarser particles.

One of the most innovative aspects of the IMPROVE LIFE programme has been the gathering of a detailed **chemical database** comprising > 400 analyses not just of PM present in subway platform air, but also of the train parts and other subway materials likely to contribute to these inhalable particles (including rock ballast, catenary, electric brushes, pantographs, brake pads, rails and wheels). Our studies prove that subway air is chemically peculiar and quite unlike air breathed above ground. Concentration ranges at subway platforms for the four dominant chemical components in subway $PM_{2.5}$ are: ferruginous (Fe_2O_3) 4-52µg/m^3; carbonaceous 7-24µg/m^3; mineral dust 3-9µg/m^3; SIC 1-5µg/m^3. Iron particles in the subway derive mostly from the wear of steel wheels and rails, and ferruginous brake pads. Carbon particles are sourced mostly from pantographs, brakes and electric brushes. One novel and quite remarkable observation from the IMPROVE study is that the metallic trace metal components of specific moving train parts can easily be recognised in subway air, and it prompts questions about the **toxicity** of these materials. Further research and development to produce materials that emit fewer and less toxic particles would be a positive way forward. Meanwhile we recommend a phasing out of Cu-rich catenary materials and of brake pads containing enrichments in more toxic metals and metalloids such as Sb.

Given the complicated nature of the problem, in order to improve subway air quality we recommend a co-ordinated approach that recognises the different issues involved. The first step should be an initial **air quality audit** aiming to assess the nature of the existing air quality in stations and trains. The audit should compare all lines in the subway system, noting those involving large numbers of curves and significant gradients likely to have an effect on brake emissions, and gather data on the chemistry of brake pads fitted to the trains. This initial study will obtain measurements of inhalable PM concentrations on platforms and inside trains. The detailed chemical database obtained by IMPROVE LIFE need not be repeated although some need for chemical analysis may emerge for those subway systems that exhibit unusual characteristics, such as the use of rubber tyres. We recommend measuring platform air quality under different ventilation airflow speeds and directions. Outdated fan ventilation systems should be replaced by new, more efficient designs. Ideally ventilation inlets should be raised above ground to lessen the inflow of traffic-contaminated air, although practical difficulties with any social impacts induced by installing raised towers blocking the street view will need to be addressed. The operating system needs to be designed to minimise the movement of air from the tunnels into the platform. Finally, the IMPROVE study has conclusively demonstrated the beneficial effect of platform screen doors (PSD) on platform air quality. The increasing use of PSD systems worldwide is to be strongly encouraged not just for passenger safety but also for cleaner air, although they must be full length (floor to ceiling) to minimise the ingress of contaminated tunnel air.

Policy effectiveness and socio-economic impact

IMPROVE LIFE has emphasised the necessity of knowing the quality of the air breathed in subway platforms and trains, developing a methodology that can be applied worldwide by the relevant authorities and policy makers. The results from our intensive studies are provided in two Deliverables: PM contributors and potential mitigation measures in the subway environment; and Technical Guide to improving subway air quality. In addition, 2 questionnaires were prepared: one involving direct contact with subway passengers and carried out by TMB, and a second one published in the web page of the project (results and conclusions of this activity are given in the Deliverable 11: Questionnaires for the public).

IMPROVE results have generated strong interest in all presentations to other subway systems and international institutions related to public transport. Various meetings with stakeholders to present and discuss IMPROVE LIFE results have been carried out, including: Metro Bilbao, Metro Valencia, Metro Sevilla, Metro Madrid, Renfe, Adif, Ayuntamiento de Barcelona, TMB health and safety committee, Transport for London, Vienna Subway, and the International Association of Public Transport (UITP). In the 25th UITP Sustainable Development Commission meeting the IMPROVE LIFE technical guide for improving air quality in the subways systems was considered as a keynote reference publication to which all future mitigation actions should be referred, especially with respect to the innovative colour-coded diagram for subway air quality improvement presented in the guide.

New business and employment opportunities in the area of improving air quality in the subway system during the project and after its finalisation include:

- the market of nanopolymers. This benefited from IMPROVE LIFE project as the efficiency of nanopolymers to mitigate dust resuspension while adding and manipulating ballast has been tested during several night-time tunnel activities in Barcelona subway system.

- the manufacture and installation of PSD systems in subway platforms. The project has shown this measure as one of the most practical to reduce PM concentrations on platforms.

- mechanical/electrician workers to plan and control (flow direction and intensity) the best ventilation protocol for both tunnel and platforms.

- IMPROVE LIFE created full time new jobs of 3 specialized scientists and 1 administrator, all of them women, working in CSIC for this project.

Dissemination

Dissemination of the project has been successfully wide-ranging and the obtained results, along with the consequent suggested measures to improve the air quality in platforms and trains of subway systems, have been widely publicized.

- IMPROVE LIFE participants have had meetings with 12 subway national and international authorities and stakeholders.
- The project featured in 5 TV programmes, 51 web and press releases, 10 radio interviews.
- Further publicity included a user-friendly website http://improve-life.eu/, 2 informative videos in English, Spanish and Catalan, a Layman's Report, 1 leaflet, notice boards, 16 publications in scientific journals, 2 publications in EU magazines, and a technical guide on air pollution mitigation delivered to subway stakeholders and policymakers.
- Organisation of one International Conference (RICTA 2017), Organisation of two workshops (SETAC), 18 presentations in international conferences, Participation in 6 events, Organisation of one LIFE networking event (LIFE PLATFORM MEETING ON AIR QUALITY 2017), Networking with other LIFE projects.

Financial part

Chapter 6 comments on the financial report: The IMPROVE LIFE project has a total budget of 813.728€ and received a pre-financing amount of 162.746€ (40%) and a further payment of the same amount was received after approval of Mid-Term Report, adding a total of 325.492€. By the end of the project, 31/03/2018, the total cost of the project was € 808.228,69€, less than 1% under the budget foreseen in Grant Agreement.

When compared the foreseen with the executed budget, the allowed flexibility of 30,000€ and 10% (cf. Article 15.2 of the Common Provisions) is respected, as no category increases over this threshold (see tables on chapter 6).

The final costs of IMPROVE complies with the rule on Art.25.2 of CP defined as follows: "…the sum of the public organisations' contributions to the project must exceed (by at least 2 %) the sum of the salary costs of the civil servants charged to the project" exceeding by 2,3% (tables on chapter 6).

The standard statement of expenditure has been implemented and periodically updated by the Project's Financial Manager, as well as by each partner for its own expenses. Expenses from all beneficiaries were collected every 3 months, and the project updated by the CB. The LIFE+ timesheet model was used for electronic time recording. Time was registered on a daily basis, printed and signed monthly, and sent to the CB every 3 months. In the case of TMB-FMB, technical staff that participates sporadically (less than a 2 day/month average) according to article 24.2 of Common Provisions 2013, do not present time-sheets. This corresponds to sporadic technical support to field campaigns.

All relevant administrative, technical and dissemination annexes are included in **Chapter 7**.

3. INTRODUCTION

Environmental problem addressed. The use of public transport to abate urban atmospheric emissions is to be encouraged, and in this context subway systems are especially desirable as they are based on electric trains, are energetically efficient, and help diminish surface traffic congestion. However, in response to increasing awareness of the importance of clean air to human health, a number of studies have revealed unacceptably high levels of inhalable particulate matter (PM) in some subway systems. Furthermore, in addition to relatively coarse abrasion particles derived from brakes, rails and wheels, the presence of highly respirable ultrafine metallic PM linked to train movements has also been demonstrated.

Hypothesis to be demonstrated/verified. The project hypothesised that air quality in the subway system can be improved. To demonstrate this IMPROVE LIFE targeted and identified the main PM emission sources in this environment and found ways of reducing their effect on subway air quality, elaborating mitigation strategies to reduce PM concentrations in platforms and inside trains.

Description of the technical/methodological solution. Complementary methodologies were used to compare air quality between old and new subway lines, different platform designs, different catenaries, with trains using different brake pad compositions, different air filters inside trains, under differing ventilation conditions in platforms/tunnels, and after different tunnel activities. Techniques included continuous monitoring of PM, particle size distributions (0.3-20µm), CO and CO_2, NO_2 (passive samplers) as well as complete chemical analysis of inorganic and organic (PAHs) compounds in $PM_{2.5}$ quartz microfiber filters (HVS), and morphological and size analysis of individual particles by means of both SEM and TEM. Receptor models (PMF) were used for the source apportionment study, which revealed to what extent particles were related to each source. This information can then be considered as to which PM sources should be prioritised in order to reduce the emissions most effectively.

Expected results and environmental benefits. IMPROVE LIFE aimed to demonstrate how to achieve a reduction in subway inhalable PM concentrations, and thus improve life quality for the millions of people daily travelling by subway worldwide as well as for subway workers. These results were elaborated in a technical guide that has been distributed to EU transport authorities responsible for air mitigation measures as well as other interested parties worldwide (see list in Annex XIII).

The longer term results of the project include: i) encouraging transport authorities to follow new protocols designed to improve subway air quality; ii) lobbying for a European Directive for air quality action plans in subway environments; iii) justifying the allocation of national funds focused on the implementation of air mitigation strategies; iv) encouraging authorities to create a legislation for air quality in the subway environment. The project has demonstrated how to achieve a reduction of $PM_{2.5}$ levels by applying effective air mitigation strategies appropriate for subway systems. These newly developed mitigation strategies are being promoted to encourage their adoption in other subway systems worldwide.

4. ADMINISTRATIVE PART

4.1 Description of the management system

The overall coordination of the project was responsibility of the coordinating beneficiary CSIC, although the planning and execution was done jointly with the beneficiary partners (TMB-FMB and TMB-TB). Table 1 gives an overview of the project phases, tasks and activities of each action.

Table 1. IMPROVE LIFE overview. All actions coordinated by CSIC.

Action	Tasks and Activities
A. Preparatory Actions	
A1. Documentation of the current status and selection of critical parameters to be tested	To describe previous studies on air quality conditions in subway systems worldwide. Identify gaps and omissions in these previous studies. Recommend priorities with regards to the emission sources to be tested.
B: Implementation Actions	
B1. Determination of the impact of selected parameters	To determine the impact of the previously selected parameters to elucidate differences in air quality under such parameters (old/new lines, ventilation conditions, platform designs, catenaries, brake pads, air filters, tunnel activities).
B2. Testing mitigation measures and Development of mitigation strategies	To implement a series of experiments on the parameters from B1, with solutions proposed for reducing their contribution to poor tunnel and platform air quality. To elaborate a report overviewing the possible corrective measures that could be applied to reduce PM emissions in the subway system.
C. Monitoring of the impact of the project actions	
C1. Effectiveness of the project actions	To evaluate the effect of B1-B2 actions on PM levels and composition in the subway, by comparing levels and chemistry of PM before/after the studies. Air quality benefit will be calculated in $\mu g/m^3$ abated by the mitigation experiments.
C2. Assessment of the socio-economic impact	Prepare the questionnaires for the public and the stakeholders. To assess the overall impact of the project.
D. Communication and Dissemination action	
D1. Project website	To create and continuously updated IMPROVE website
D2. LIFE+ Information boards	To create and place information boards, describing the project's objectives and activities, addressed to the general public.
D3. Dissemination of project results including a Networking-Open forum	To convey the project results to the general public, stakeholders, researchers, public transport institutions and governmental institutions.
D4. Layman's Report	To produce the Layman's Report in electronic and paper format
E. Project management and monitoring of the project progress	
E1. Project Management and Audit	Scientific, financial and administrative management. Preparation of the IMPROVE reports. Audit of the financial forms
E2. Monitoring of the project progress	Monitor the overall progress. Verify the compliance with the Grant Agreement. Maintain communication between partners, Monitoring Team and the EC.
E3. Networking with other European projects	Networking with other projects and organise workshops
E4. After-LIFE+ Plan	Prepare and disseminate the After-LIFE+ Communication Plan

Project management and audit (Action E1)

The organization chart of IMPROVE LIFE, with the role of beneficiaries, persons and actions involved, is given in Figure 1. The **Project Manager** (PI) is T. Moreno from the coordinating beneficiary CSIC, overall responsible for the project. Key members of CSIC include A. Alastuey, X. Querol, MC. Minguillón and C. Reche, responsible with T. Moreno for the implementation, progress and overall impact of the project, and C. de Vasconcelos responsible for the **Administrative and Financial Management**, the continuous update of the project website, as well as for the compliance with the Grant Agreement. Furthermore, an operation group formed by personnel of TMB-TB and TMB-FMB assists in the execution of their tasks. The coordinating beneficiary CSIC is responsible for the implementations of all actions.

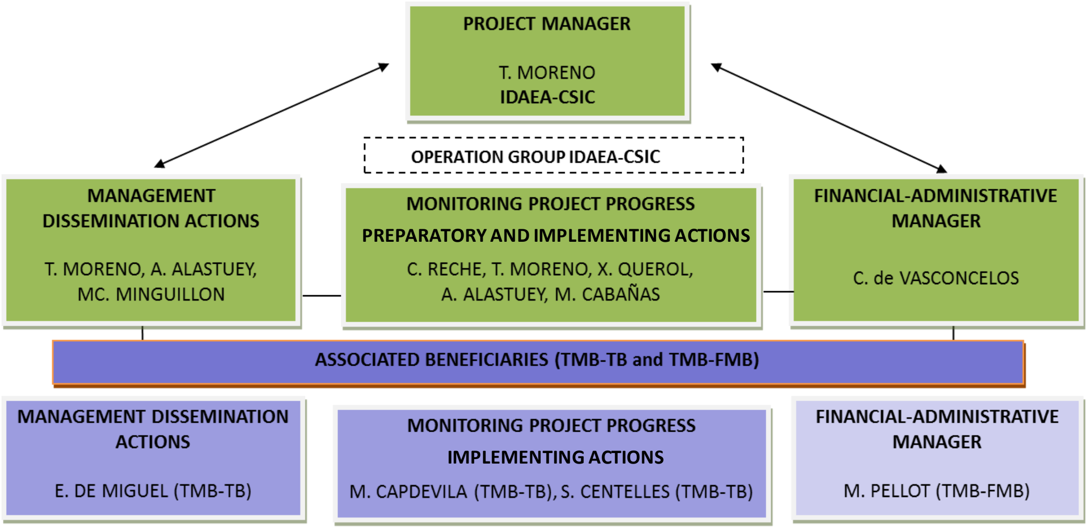


Figure 1. Management structure of IMPROVE LIFE.

Regarding organisational issues a problem was identified as the Associated Beneficiary (originally signed as TMB) included Ferrocarril Metropolita de Barcelona, SA (TMB-FMB) and Transports de Barcelona, S.A. (TMB-TB), operating in an integrated manner but with separate VAT numbers. Both the Grant Agreement (Annex Ia) and Partnerships Agreement (Annex Ib), signed by now three partners (on 07/03/2016) were therefore amended without implying any modification of the total budget already approved, or of the objectives, expected results, content and aim of the different actions of the project. Only personnel and travel costs were divided between both associated partners according to the affiliation of the personnel involved in each of the companies. The request for this amendment of the Grant Agreement was approved on 20/01/2016 by the European Commission. A copy of the original partnership agreement was included in the Inception Report, whereas a copy of the new amended version was included in the Midterm Report. The Quality Assurance Plan (QAP, Annex II) was prepared by the CB on November 2014, to be used as the main tool and method for the project management.

IMPROVE LIFE was launched by the PI T. Moreno (CSIC) at the kick-off meeting (28/10/2014), and attended by representatives of all associated beneficiaries. At this meeting the CSIC as CB presented the project, Life+ Common Provisions and emphasised key issues concerning reporting and other obligations with the European Commission. Decisions with regard to the preparation of the partnership agreement, the management team of the project, and technical issues were taken by all partners. All beneficiaries work closely with the project and the financial manager, and thus although the project management team was scheduled to meet every three months, a total of 48 meetings took place during the project, including meetings related to the development of implementation actions, and updating administrative and financial issues. A list of all meetings with the names of participants is given in Annex III.

4.2 Evaluation of the management system

Monitoring of the project progress (Action E2).

The management of the project has paid close attention to progress within the scheduled timetable, as documented by the completion of deliverables and milestones, and some adjustments to deadlines have proved necessary. Action B1 was extended 3 months until September 2016, as chemical results were not finished by June due to the large number of samples. Similarly, B2 benefited from an extension until June 2017, due to both i) mechanical problems with the equipment necessary to add ballast to the rail tracks, and ii) an over-optimistic originally proposed date by which to finish the monitoring campaigns (09/2016). These adjustments to the deadlines gave more time for the deliverable associated with action B2 (*Elaboration of a technical guide for mitigation measures*), which is one of the most important results of the project. The modification of the duration of both Implementation Actions was discussed with the LIFE Monitoring Team (NEEMO) during their visit in June 2016, and explained in the letters sent to the European Commission on 22/07/2016 and 28/03/2017. Accordingly, Action D4 (Layman report) started in January 2017, instead of July 2016, a modification also approved by the Monitoring Team. Finally, the one-day workshop with other European Projects, which was scheduled to take place before 30/06/2015, was hosted in 2017, when the results of IMPROVE LIFE were further advanced. The workshop was hosted by the IMPROVE and AIRUSE projects as a LIFE Platform Meeting on Air Quality that took place on 26-27/09/2017, under the title: *Abating urban exposure to air pollutants*. The International LIFE Platform reviewed the state of the art strategies and measures to produce better air in the cities where we live. Speakers presented their views on this matter aiming to prepare helpful guidelines for all European cities. The meeting was structured in 3 sessions: Urban Air Quality Measures, Citizen Exposure While Commuting, and Models and Tools for Air Quality Management (presentations are available in http://improve-life.eu/event/).

The management of the project has paid close attention to progress within the scheduled timetable, as documented by the completion of deliverables and milestones, and some adjustments to deadlines have proved necessary. A Gantt chart for the whole lifecycle of the IMPROVE LIFE project is shown in Figure 2. Every 3 months a summary review was prepared, where all launched and accomplished activities were reported as well as deliverables and dissemination actions. The Deliverable 21 contains the 14 summary reviews of the project progress. The progress of the project is also assessed according to the Indicators of Progress (Annex IV), with the state of each action to highlight any signs of delay or inefficiency.

Communication with the Commission and Monitoring Teams. The first meeting with the representative of the Monitoring Team (Mrs. R. Asensio) took place at the premises of IDAEA-CSIC in Barcelona on the 13/05/2015. The second meeting took place on 13/06/2016, the third one on 01/05/2017 and the final on 26/06/2018, this last one in TMB main offices in Barcelona. A fluid and regular communication with the Monitoring Team has been maintained by e-mail and phone, insuring full understanding of procedures and ongoing work programmes.

The inception report, covering activities until 30/06/2015, was prepared by the CSIC Coordinator and reception of this was acknowledged by the Commission on 6/07/2015. The LIFE+ Desk officer found it "*of high standard with informative description of project activities carried out*". On 18/03/2016 the amendment to the original Grant Agreement was signed by the European Commission. Finally, the Midterm report was sent to the Commission on the 05/01/2017.

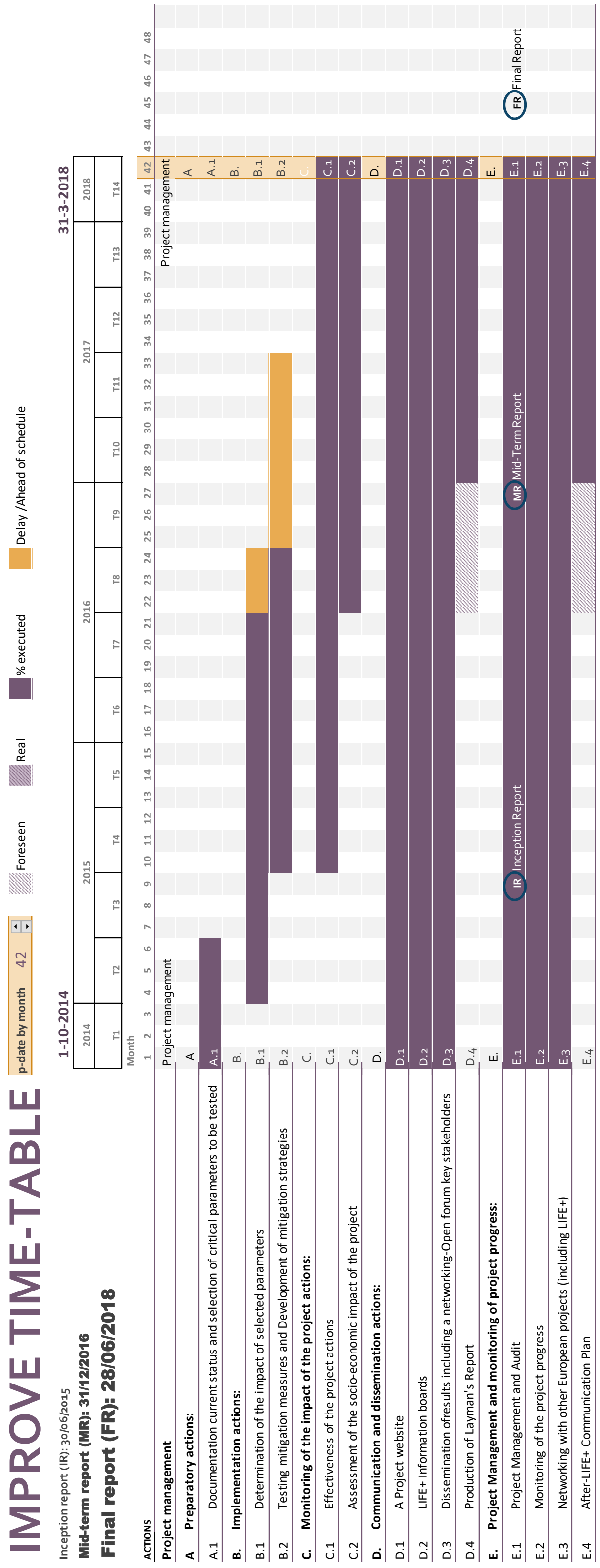


Figure 2. Progress of the project and the planned actions.

5. TECHNICAL PART

5.1. Technical progress, per task

A list of abbreviations is shown in Annex V.

5.1.1 Action A1 Documentation of current status and selection of critical parameters to be tested

From October 2014 onwards the coordinator CSIC prepared a literature review (C. Reche and T. Moreno) of a total of 62 studies conducted on subway systems in 30 different cities worldwide (as documented in Deliverable 2, January 2015, Figure 3). The review includes information on the location and time duration of each study, measuring equipment used, frequency and number of samples collected and chemical species analysed, as well as the main pollution sources identified. Average values for each parameter studied in each study are also shown.

The monitoring equipment and location have varied considerably in these different studies and in some cases have led to contrasting conclusions, demonstrating a lack of standardisation that makes it difficult to compare results between subway systems. Some studies have reported higher levels of PM in the subway system (e.g London, Barcelona, Stockholm) compared to other modes of transport, while other studies reported lower levels (e.g. Hong Kong, Guangzhou, and Mexico City). The few studies that include chemical characterisation all agree however on the high contribution of Fe, which is typically associated with friction processes between wheel and rail, brake abrasion, and the abrasion of power cables and third rails. Similarly, a common enrichment in Cu compared to outdoor levels is generally attributed to copper lines for power transmission, while Mn is (like Fe) released from abrasion of the subway steel rail and train wheels.

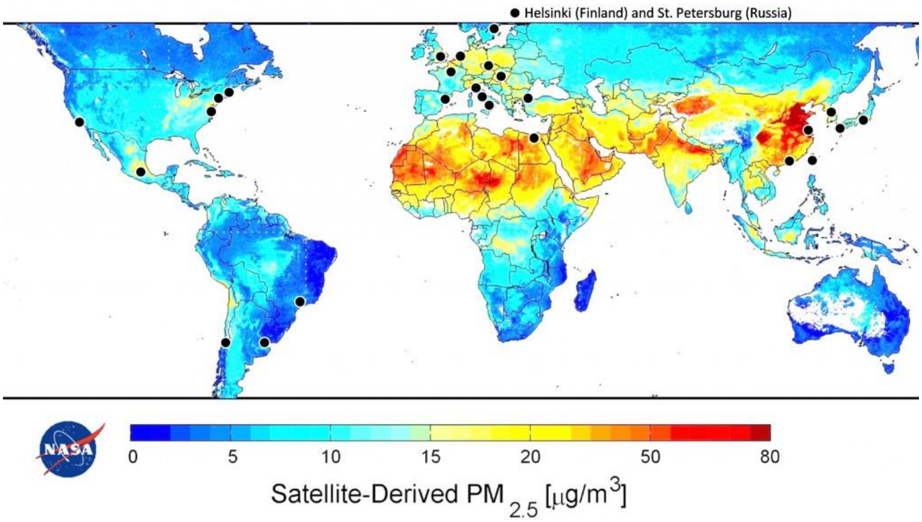


Figure 3. Location of cities where studies of subway air quality have been published. World map from NASA showing satellite-derived $PM_{2.5}$ concentrations in ambient air.

Most (93%) of the subway air quality studies have focused on particle mass concentration, with only nine of them measuring air quality inside trains (usually PM levels), and only two of these measuring particle numbers or present chemical composition data. In the more frequent measurements in subway platforms half of the studies have chemically characterised PM samples, although only four have analysed organic components. Also very rare is the register of gaseous components such as CO_2, CO or NO_2 (3% of the cases). When studying PM in the subway platforms 39% of the studies present PM_{10} and/or $PM_{2.5}$ concentration data (most commonly using DustTrak equipment), less frequent is the concentration of number of particles (16% of the studies). Chemical analyses have been performed on PM collected in a wide variety of filters, including quartz-fibre, Teflon, nitrate cellulose or polycarbonate, and only very rarely were passive samplers used. The number of samples collected is very variable, most commonly in the 20-50 range, with very few having a number of samples above 50 (4 studies).

Although up to 27 scientific publications discuss the possible sources emitting airborne particles within the subway environment, there are only data on the contribution of each source to the total PM mass in four subway systems. The sources identified in these studies are in order of number of citations (in brackets): wheels abrasion (18), brake wear, both discs and pads (18), rails abrasion (17), wires, electrical supply (10), mineral dust (8), outdoor contamination including secondary inorganic compounds and traffic (6), ballast erosion (3), rubber tyre wear (1), oil combustion (1) and solvent emissions (1).

In spite of this general recognition of likely sources of particulate matter (PM) in ambient air on platforms and inside trains, only a very limited number of studies include an analysis using well-established receptor/statistical models for the quantification of the contribution of the different contaminant sources. Deliverable 4 comments on these source apportionment studies of the subway environment applying receptor/statistical models to identify and quantify the contribution of the possible PM sources.

Deliverable 4 also highlights the lack of published work quantifying the contribution of indoor sources in underground metro systems under different platform designs or ventilation conditions, with most of these studying only the PM_{10} size fraction. The metro system of Seoul is the only one which includes a detailed characterization of factors affecting the air quality, whereas in contrast similar information remains very limited in European cities. According to the studies examined the contribution of indoor-generated sources on platforms ranges between 44 and 69 %, with the lowest percentage corresponding to a station with platform screen doors (PSD). In order to more fully characterize passenger exposure in metro systems, reduce emissions and propose a good practice guide for future subway line constructions, more detailed source apportionment studies based on a large number of samples and analysed chemical species are clearly needed.

Following the conclusions from the deliverables of Action A1, the main parameters to be emphasised in future subway air quality studies were identified as follows:

- particle mass concentrations
- inorganic and organic chemical composition
- black carbon concentrations
- particle number concentrations and size distribution
- microscopy (for size, shape and chemical composition of individual particles)
- toxicity
- bioaerosol concentrations
- concentration of gases such as NO, NO_2, CO, CO_2 and ozone concentrations
- identification of contaminant source (source apportionment)

As originally planned, the examination of these reports facilitated the determination of the main parameters on which to focus in IMPROVE LIFE, and revealed the existence of obvious gaps in knowledge. In order to obtain the most comprehensive database in IMPROVE we needed to monitor the maximum number of parameters, including not only those most commonly shown in other studies (i.e. particle concentrations and inorganic chemistry), but also others less frequently studied such as particle numbers, size distribution, organic chemistry, microscopy studies, bioreactivity, gaseous components, combined with a detailed source apportionment study based on a large number of samples. Careful selection of these parameters enabled us to move forward on to the development of the implementation actions.

This action did not suffer any delays.

Table 2. Summary progress of Action A1

		2014	2015				2016				2017				2018
Action		IV	I	II	III	IV	I	II	III	IV	I	II	III	IV	I
A1	Foreseen														
	Actual														

Deliverable		Deadline	Status
2	One historical PM level and chemical composition database	31/01/2015	Completed
4	Review on air pollutant sources and suggestion of parameters to test	31/03/2015	Completed

Indicators of implementation	
Catalogue/describe previous studies on air quality conditions in subway systems worldwide	Achieved
Documentation of the air pollutant sources identified for this historical dataset	Achieved
One list of prioritisation of pollution sources and selection of parameters to test.	Achieved

Continuation after LIFE: This action will not continue after the project end date.

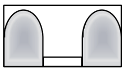
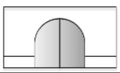
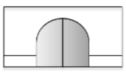
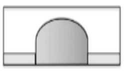
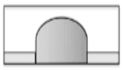
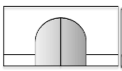
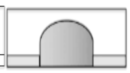
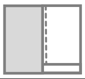
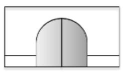
5.1.2 Action B1 Determination of the impact of selected parameters

To meet the objectives proposed in Action B1, air quality monitoring campaigns were performed focused on variations in key factors affecting subway air quality. These sampling campaigns included some specifically aimed at assessing the impact on passenger exposure to air pollutants after making changes to normal conditions on platforms and inside trains. In this context, from January 2015 to September 2016, sampling campaigns carried out in the framework of this action followed four main purposes: to check the impact on passenger exposure to air pollutants attributed to (1) maintenance works in tunnels, (2) use of different brake pads, (3) use of pantographs with different composition (copper versus graphite), and (4) the deterioration of air conditioner filters inside trains. The main characteristics of the metro stations where measurements have been carried out are reported in Table 3, which includes information on the opening year, depth and station design. The same sampling protocol was applied on the platform of all the selected metro stations during the project. Sampling devices were located at the end of the platform corresponding to the train entry point, behind a light fence for safety protection. Examples of the positioning of the air quality instrumentation at platforms can be seen in Figure 4. The monitoring campaigns were organised and controlled by

C. Reche and T. Moreno (CSIC), and M. Capdevila, S. Centelles and E. de Miguel (TMB); in addition, they required the participation of technical personnel from both TMB partners, including electricians and infrastructure technicians. Equipment maintenance was executed by C. Reche (CSIC).

Figure 4. View of the disposal of air quality instrumentation at the platforms of the subway stations

Table 3. Comparison between the metro stations where air quality measurements have been carried out in the framework of the IMPROVE project.

	Sagrera	Palau Reial	Maria Cristina	Tarragona	Santa Coloma	Joanic	Sant Ildefons	Collblanc	Poble Sec
Metro line	L5	L3	L3	L3	L1	L4	L5	L9	L3
Opening	1959	1975	1975	1975	1983	1973	1976	2016	1975
Depth	10.5	14.2	13.7	14	12.3	7.6	14	60	14
Station design									

(1) <u>Maintenance works in tunnels</u>: the first measurement campaign was carried out in the underground station of **Sagrera** from 20th of January to 1st April 2015, where major works were planned aimed to mitigate track vibrations at the station by replacing ballast, sleepers and rails. In addition, to evaluate in more detail the effect on air quality of rail replacement in tunnels and platforms, two more sampling campaigns were performed. The first one took place at the metro station of **Santa Coloma** (L1) from 1st October to 3rd November 2015, and the second at **Joanic** (L4) from 3rd November to 22nd December 2015. Both sampling periods included days under normal conditions and days affected by works related to the replacement of rail tracks, consisting of i) material transport using diesel vehicles, ii) rail replacement including abrasive cutting with gasoline-powered machinery, and iii) welding work.

The contaminating effect of tunnel night work on platform air quality was clearly demonstrated by the several experiments designed to measure such events during the IMPROVE LIFE campaigns. On the platform of Sagrera station, for example, median night-time levels of $PM_{2.5}$ rose by >50% during most of a 7-week campaign of work involving rail track removal and replacement. However, such average values hide the fact that the additional pollution produced by night maintenance activities typically occurs as short-lived episodes of very high PM levels. $PM_{2.5}$ levels during such episodes commonly exceed 200µg/m^3 (Figure 5), and in extreme cases can peak above 1000µg/m^3 (5-minute value) when adding new ballast, > 900µg/m^3 when doing welding operations or > 800µg/m^3 when heavy vehicles transporting material pass the measuring station.

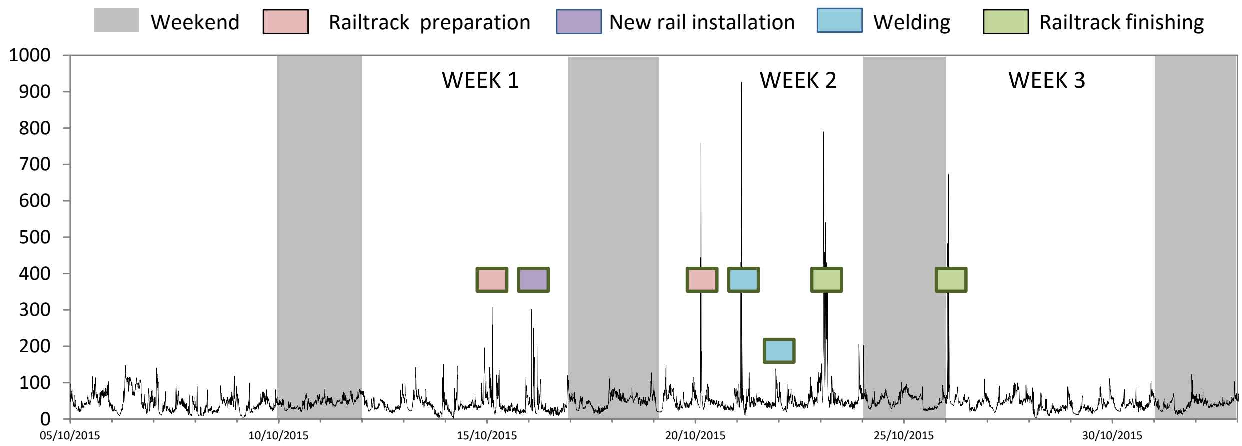


Figure 5. Time series of $PM_{2.5}$ (µg/m^3) at Santa Coloma station demonstrating transient peaks produced during night maintenance works.

Any additional dust burden generated within the subway system during the night has the potential for damaging air quality for the commuters using the trains during operational hours. The data obtained during measurement campaigns conducted at several stations all demonstrate that dust emissions from tunnel night work typically result in poorer platform air quality at the beginning of daytime train operations. This additional airborne PM loading declines over the working day as the extra dust burden is diluted and redistributed by train movement and ventilation. At Sagrera, for example, the additional works-related extra $PM_{2.5}$ loading on the platform at the beginning of the day was commonly around 10µg/m^3. In some cases however, the extra early morning "works generated" dust burden can exceed 30µg/m^3, as demonstrated by the data from Santa Coloma station shown below (Table 4).

Table 4. Median $PM_{2.5}$ concentrations (5-minute µg/m^3 values) on the Santa Coloma platform calculated for 1, 4, 8 and 19 hours during the day after night tunnel works.

	Median			
	05-06:00	05-09:00	05-13:00	05-24:00
15/10/2015: Railtrack preparation	75	42	32	28
16/10/2015: New rail installation	50	39	28	28

The increase in ambient pollutants present on platforms after night works could also be detected by chemically analysing $PM_{2.5}$ samples (MC. Minguillón from IDAEA-CSIC). These chemical data revealed that the most obvious effect of night-works was seen after rail removal and replacement activities, rather than following the transport of materials to the tunnel work site. Figure 6 shows the ratio between the concentrations of trace elements during days when works took place and the concentrations during normal conditions (no works). The ratios exceeding unity indicate how the concentrations of most of the trace elements increased during works.

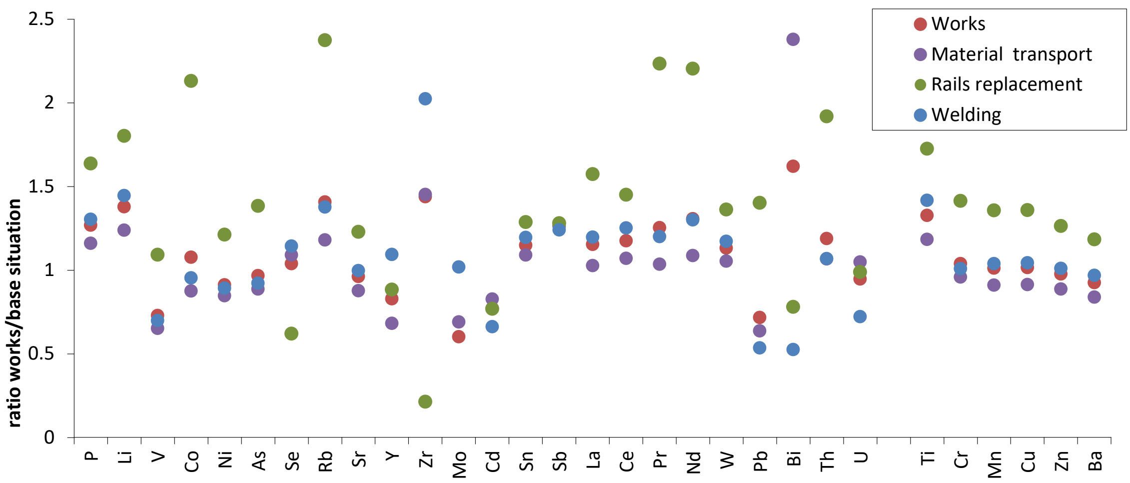


Figure 6. Ratio between concentrations of trace elements at Santa Coloma station during days when works were carried out with respect to days when no works took place. The red dots represent averages of all work nights, and the other colours are the ratios for specific activities.

(2) <u>Use of different brake pads</u>: Four different types of brake-pads, and both lateral and frontal braking systems, are used in the Barcelona subway and they show distinctive trace element chemistries, with varying enrichments in amounts of Ba, Fe, Cu, Zn, Ca, Mg, S, Mn, Sr, Mo, and Sb all contributing to the chemistry of Barcelona subway air (see analyses presented in Table 8 of Deliverable 8). Friction-generated particle emissions generated from these brakes as the slowing train enters the station will contribute to ambient PM present on the platform. We estimate broadly that in some stations brake PM can form up to 40% of $PM_{2.5}$ mass present in the platform air. Such particles can be viewed under the electron microscope and are typically flakes measuring a few microns in size and with a strongly heterogeneous chemical structure. These brake flakes will be swept through and settle in the station under the diminishing influence of each train arrival piston effect, and therefore expected to be more common on the platform than in the tunnel or outdoors.

A major discovery of the IMPROVE project was the observation that different train brake compositions influence the chemistry of the air breathed on the platform. Thus, for example, platform air breathed in stations along Barcelona subway L3 has Ba concentrations of around 1400-1500ng/m^3, whereas platform air along L2, L4 and L5 contains Ba levels <150ng/m^3. By comparison, average concentrations of Ba measured in the Barcelona outdoor city background station are 5ng/m^3, so that subway Ba levels in L3 are around 300 times higher than above ground. The reason for such a tremendous increase in Ba is attributed to the fact that 80% of the brakes used on line L3 contain exceptional amounts of this element (Ba 33,000ppm). The darker, more carbonaceous component present in these chemically heterogeneous brakes contains nearly 5% Ba. No other subway PM source is Ba-rich so that most ambient Ba breathed on platforms along this line (around 1µg/m^3) can be confidently attributed to particles released during brake wear. The observation also applies to other elements, so that Ba-rich brakes preferentially contaminate subway air not only with Ba but also Sr, Zr and Ti. Similarly Sb-rich brakes produce enrichments in ambient Sb that can be 40 times higher than in stations of other lines and 100 times higher than in outdoor city air.

The most common element released by brakes overall is carbon (all brakes contain >25%C) and their wear makes a considerable contribution to the amount of ambient carbon in the subway atmosphere. We estimate that in some cases this contribution may be 5µg/m^3 or more, although given the multiple sources involved (notably pantographs, electric brushes, infiltration of C in outdoor air) more exact apportionment cannot be calculated with any confidence.

(3) Use of pantographs with different composition (copper versus graphite): The sampling campaign in **Joanic** (L4) from 3/11-22/12/2015 also permitted us to study the effect of Cu pantographs in this line compared to the graphitic pantographs used in the rest of the Barcelona subway lines. Both Mg and Cu contents of platform $PM_{2.5}$ can also be traced in part to brake emissions, although other sources are also implicated, namely pantographs for Cu and ballast for Mg. Looking at the scatter plots between Cu, Fe and Cr in ambient $PM_{2.5}$ sampled from subway platforms (Figure 7) different groupings reveal chemical differences in ambient air between different stations. The yellow line (L4) clearly shows the highest Cu concentrations, which is consistent with the fact that Cu pantograph is used in this line for 30% of the trains, while only graphite pantographs are used in the other subway lines. For further details see [Deliverable 8 (PM sources in the subway environment)](#).

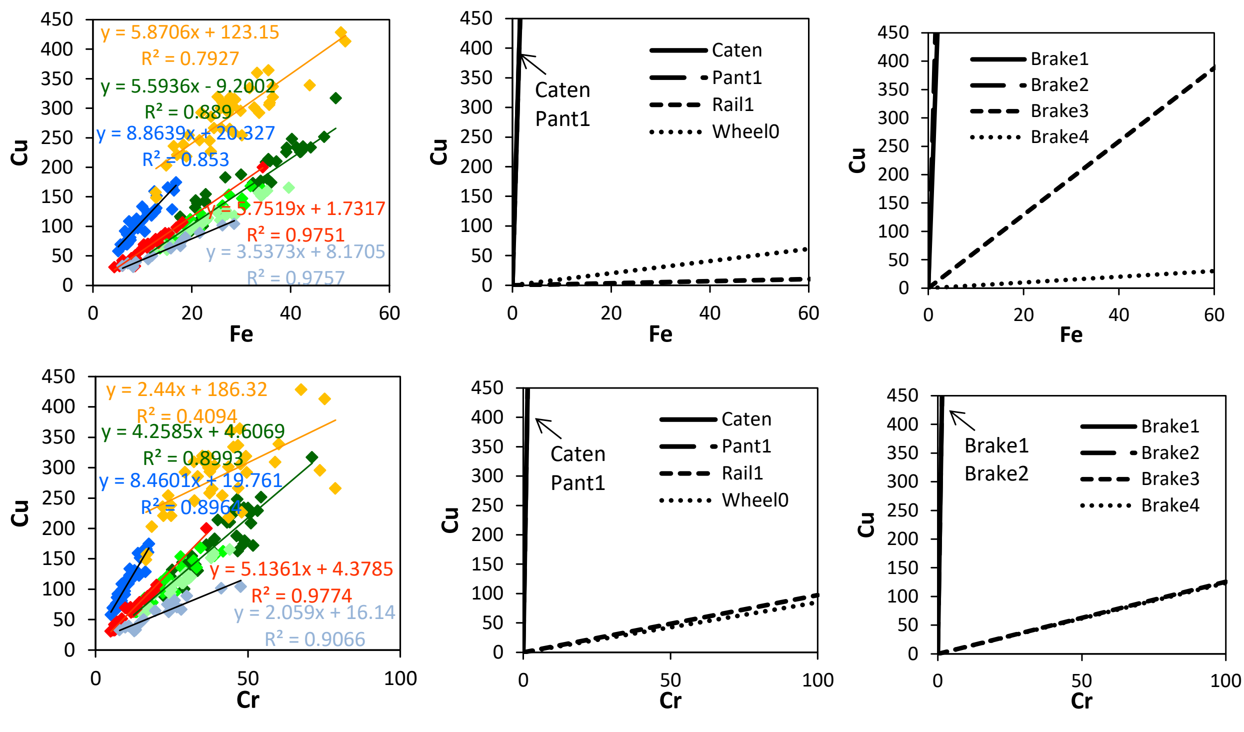


Figure 7. Scatter plots comparing concentrations of chemical tracers present in ambient air of six metro stations , as well as the relevant ratios for train rails, wheels, pantograph, and catenary: Cu vs Fe and Cr. Cu and Cr concentrations are in ng/m^3 and Fe concentrations are in µg/m^3. Colours relate to different stations (red = Santa Coloma L1; very pale green = Tarragona, light green = Maria Cristina, dark green = Palau Reial L3; yellow = Joanic L4; pale blue = Ildefons L5; dark blue = Sagrera L5).

(4) Deterioration of air conditioner filters inside trains: Air quality inside trains in the Barcelona subway system is always better than on platforms. During one IMPROVE LIFE experiment (on the L3 line) for example, mean $PM_{2.5}$ levels during subway operation hours were 30–50% lower than those recorded on platforms of L3 stations during the same period. One reason for this is that Barcelona subway trains travel using air conditioning within a closed system that does not allow open windows. From the measurements carried out with and without air conditioning, one can conclude that the air conditioning produces a notable improvement in both concentration and variability of PMx inside the trains, especially for the coarser particles.

In order to check the effect of the deterioration of air conditioning filters on air quality inside trains, a DustTrak monitor was installed inside one of the driver's cabins in one train of L3 (air inside this cab is representative of the passengers' exposure as it has the same ventilation system as the rest of the carriage). Measurements started on 2nd April 2015, when all air conditioning filters along the train were replaced (TRAIN 1, Table 5). Filters were changed again after one month, on 2nd May 2015, following the established TMB protocol. These filters were maintained until the end of the campaign on 3rd July, in order to evaluate the effects on air quality of extending the service life of filters from one to two months. To investigate the reproducibility of the results, a second campaign was carried out in a different train of L3. PM measurements started on 10th July and finished on 15th September 2015 (TRAIN 2). In this case, however air conditioner filters in the selected train had been changed one month before the beginning of the sampling campaign, and were not replaced again until the end of the campaign, that is after being 3 months in use.

Table 5. Details of the sampling campaigns carried out inside trains showing mean concentrations of $PM_{2.5}$ measured inside a train across three monitoring periods with the same A/C filter.

Location of equipment	Air conditioning filters changed	PM measurements	Filters days in use
TRAIN 1 Intermediate driver cabin	02/04/2015 05/05/15	02/04/15-04/05/15 05/05/15-03/07/15	33 days 59 days
TRAIN 2 Intermediate driver cabin	10/06/2015	10/07/15-14/09/15	90 days

$PM_{2.5}$ (µg/m^3)	*Weeks after changing AC filter*												
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*
Train 1 (1 month)	40	47	43	43									
Train 2 (2 months)	41	41	40	36	31	38	33	32	30				
Train 3 (3 months)				46	43	35	33	31	32	31	35	34	35

These campaigns produced several interesting results: (a) $PM_{2.5}$ levels inside the train were higher (c.20%) during weekdays as compared to weekends (45 and 35µg/m^3 respectively), emphasizing how train frequency is a key parameter controlling the PM levels in subway systems; (b) high amplitude transient peaks recorded during the measurements were related to activities during non-operational hours when the train was located in the parking area (e.g. graffiti removal, technical cleaning with compressed air and other forms of cleaning); (c) NO_2 concentrations inside the train averaged 47±4µg/m^3, this being 25-30% lower than on platforms; and (d) the air quality benefits of operating air conditioning inside train carriages are maintained for at least three months without changing the filters. If energy efficiency is similarly unaffected over this time span (or more), then there is a strong case for revising existing protocols requiring monthly replacement of such filters.

All platform measurements scheduled under Action B1 were successfully completed on time (June 2016), however delays in laboratory scheduling forced adjustments to originally proposed deadline dates. These adjustments were discussed with the LIFE Monitoring Team from NEEMO EEIG during their visit in June 2016, and thus it was agreed to shift forward deadlines for ending all measurement campaigns and completing the chemical analyses for September 2016.

A report on main air pollutant sources contribution was elaborated by MC. Minguillón (CSIC) and is given in Deliverable 8. Annex VI: IMPROVE LIFE progress reports of Actions B1 and B2 provides the four technical reports prepared every 6 months by the T. Moreno, C. Reche and MC. Minguillón (CSIC) team, along with the advancement level of the campaigns and analysis. A report on "Concentrations of chemical tracers for PM sources in subway systems (database)" is presented as Annex VII.

Table 6. Summary progress of Action B1

		2014	2015				2016				2017				2018
Action		IV	I	II	III	IV	I	II	III	IV	I	II	III	IV	I
B1	Foreseen														
	Actual														

Deliverable		Deadline		Status
		Project	Solicited	
8	Report on main air pollutant sources contribution	30/06/2016	30/09/2016	Completed

Indicators of implementation	
Technical reports will be produced every 6 months	Achieved
Construction of one available database detailing the concentrations of chemical tracers for pollutant sources in subway systems	Achieved
Identification of main pollutant tracers	Achieved
Preparation of a report overviewing and comparing the full impacts on air quality of each of the selected parameters	Achieved
Completion of source apportionment study based on the full dataset of chemical analyses, and quantitative elucidation of the relative importance of each source	Achieved

Continuation after LIFE: This action will not continue after the project end date. The results from this action will be used after the finalisation of the project by subway authorities, researchers, and other interested groups, providing what is to date the most comprehensive source of data regarding air pollutant concentrations and sources in the subway systems.

These data will be of immediate use as comparative information during new campaigns to study urban transport emissions, such as the newly awarded BUSAIR project, which will again involve collaboration between TMB in Barcelona and CSIC (T. Moreno). This project, aimed at the study of bus emissions, will last from 01/2017-12/2019, and is financed by the Spanish Government (CGL2016-79132-R-BUSAIR, 128.000€).

5.1.3 Action B2 Testing mitigation measures and development of mitigation strategies

A further step of this project involved the proposal and field implementation of mitigation strategies to reduce the effect on indoor air quality of pollution-generated activities, which is referred to in action B2. The addition of new ballast to tunnels has been selected as a key activity, likely to alter the air quality on platforms. Thus, this activity was planned to be developed under two different methodologies to assess differences: 1a) adding ballast under normal conditions (ballast+water), 1b) adding ballast using a commercial available anti-resuspension polymer (ballast +water + dust suppressant). In addition, other sampling campaigns were scheduled to check the impact on passenger exposure on platforms to air pollutants attributed to changes in the ventilation system (2), testing air purifiers (3) and having platform screen doors (4).

1) Addition of ballast: Chemical dust suppressants have been used widely above ground on road surfaces and in the minerals industry, with mixed results. They are most efficient at reducing dust levels under conditions of high dust loading, low solar radiation, and low humidity. Within underground train systems, high levels of silicate rock dust can be generated during the laying of ballast, in a situation comparable to those processes involving non-exhaust fugitive dust emissions above ground (e.g. road dust and construction works).

With the problem of night work emissions in mind the IMPROVE LIFE project pioneered the application of a polymer-based dust suppressant to ballast rock fragments prior to the material being laid on the rail track during subway night works (Figure 8). The effect on platform air quality was compared to a similar work programme in which the ballast was simply washed with water, with no application of dust suppressant. Measurements were carried out at three stations, Palau Reial, Maria Cristina and Poble Sec, all from L3. The results indicate that using the polymer-based suppressant rather than simply washing it with water produces an obvious reduction of 20-50% in night-time dust levels during ballast laying and tamping. One result of this is the reduction of any extra residual dust loading present on the platform in the early morning when trains begin operating. This dust suppression during night work translates to a lowering of early daytime platform $PM_{2.5}$ concentrations by at least 10%, thus reducing the extra loading of coarser silicate rock dust available to be dispersed through the subway system during the operating day, although the effect was variable depending on factors including distance between the platform and work site.

The increase in ambient PM mass produced during ballast-laying is particularly obvious in the coarser fraction of inhalable particles ($PM_{2.5-10}$) which we have demonstrated has a predictably "crustal" (silicate) chemical signature, strongly implicating ballast mineral dust as the likely source. The ballast used in the Barcelona subway system is a granite, and therefore is mostly composed of Si and Al, followed by Fe, K, Ca, Na, Mg and Ti. Figure 9 shows the ratio between the concentrations of major and trace elements present in platform PM during the days after usual ballast application (Palau Reial) and those after adding ballast with polymer (Maria Cristina). Values are normalised to the concentrations during normal conditions (without ballast addition). The ratios exceeding unity indicate how the concentrations of most of the trace elements increased as a result of ballast application during this activity. However, this increase was less in Maria Cristina than at Palau Reial, demonstrating an improvement in air quality which we attribute to the application of the dust suppressant polymer.

Figure 8. Mixing process of dust suppresant nanopolymer with water and application to the untreated ballast.

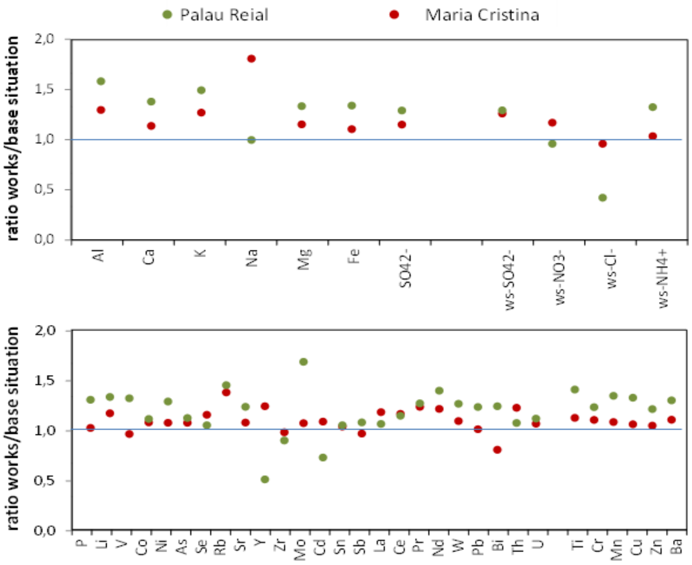


Figure 9. Ratio between concentrations of major species and trace elements during ballast addition and concentrations when no night works being carried out for Palau Reial and Maria Cristina.

2) Changes in the ventilation system: The type of ventilation system operating in the tunnels and station platforms is a key controlling influence on air quality common to subways worldwide. Subway ventilation protocols can be designed to drive outdoor air into the platforms and tunnels by impulsion or suck air out of the system by extraction, and to do this at different power settings. During our IMPROVE LIFE experimental measurement programme we demonstrated that the mass concentration of inhalable particles present on a platform can as much as quadruple in response to changing ventilation settings. Faster fan impulsion of outdoor air into the platform produces cleaner air by diluting ambient levels of subway particles, providing outdoor PM levels are not higher than those underground. Thus in our experiment on Tarragona station, with platform air impulsion average $PM_{2.5}$ concentrations were consistently and substantially (35%) higher when the fans are operating at reduced levels (Table 7). In this case therefore any power-saving benefits of reducing fan speed were seriously offset by the fact that platform median $PM_{2.5}$ concentrations rose from 61 to 82µg/m^3.

Reversing ventilation air flow from impulsion to extraction is not a strategy likely to improve air quality on the platform, especially under higher fan power settings when there can be a considerable worsening of air quality as compared to under impulsion conditions. The reason for this is revealed by the chemical data from Tarragona station which demonstrate how much of the extra PM loading comprises highly ferruginous particles of "subway" origin presumably sucked out of the tunnel by the higher fan extraction speed.

Table 7. $PM_{2.5}$ concentrations (µg/m^3) at the Tarragona platform during daytime on the days under platform impulsion and platform extraction ventilation settings.

STRONGER VENTILATION	NIGHT (00-05:00)			DAY (05-24:00)		
	Mean	Median	SD	Mean	Median	SD
Platform impulsion	*49*	*48*	*23*	*61*	*61*	*21*
Platform extraction	59	60	27	81	78	25
WEAKER VENTILATION	**NIGHT (00-05:00)**			**DAY (05-24:00)**		
Platform impulsion	*50*	*54*	*23*	*95*	*82*	*18*
Platform extraction	54	53	27	96	81	19

Modern, powerful **tunnel ventilation** systems such as those operating on the newer Barcelona subway lines have a particularly strong influence on platform air quality, even in the presence of platform screen door systems (PSD). The modern ventilation system installed at the deep station of line L9S at Collblanc, for example, involves platform air extraction fans operating at 30 Hz and two tunnel air impulsion fans operating at 37.5 Hz. If these tunnel fans are switched off then ambient platform $PM_{2.5}$ mass concentrations more than double during train operating hours (26 vs 61µg/m^3). A similarly dramatic increase in particle number concentrations occurs immediately on the platform once the tunnel fans are turned off, as demonstrated in Figure 10.

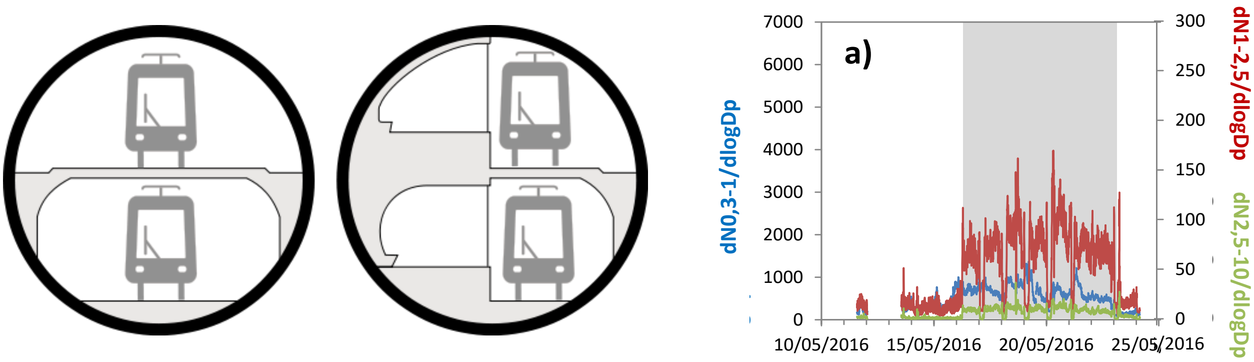


Figure 10. Sketch of the tunnel (left) and platform (centre) design in Collblanc station (Vinals, CC BY-SA 3.0 (http://creativecommons.org/licenses/by-sa/3.0), and series of particle number concentrations at Collblanc station (right) with the period without tunnel ventilation highlighted in grey.

Our measurements at Collblanc clearly demonstrate the importance of a strong tunnel fan system in reducing contamination of tunnel and platform air by subway FePM. The reduced amount of Fe in PM on the Collblanc platform, at just 4.2µg/m^3, is particularly impressive when compared with older metro lines in Barcelona. The impact of these fans on platform air quality is notable despite the presence of brand new full-length PSD which might be expected strongly to inhibit air exchange between platform and tunnel. IMPROVE data shows that with platform fans operating on extraction such a PSD system will not stop inhalable PM levels from doubling or even) quadrupling if the tunnel fans are shut down.

The Collblanc experiment offered an opportunity to examine the detailed chemical character of the "subway" FePM source. Once the tunnel fans were turned off, levels of Fe, Mn and Cr all increased by six or sevenfold. The likely main source for these "subway metals" is deduced to be train wheels rather than rails and brakes. Cobalt is another trace element similarly implicated in train wheel wear. Another group of typically "subway" trace elements that can be identified from the Collblanc database is that of Ba, Zn and Sb, all of which are implicated in particles emitted from brake wear. Antimony is most likely also being sourced from the pantograph, wheels and rail. Finally, Cu showed the most extreme increase in airborne concentration in the absence of tunnel fans, probably due to the fact that this metal is present in brakes, wheels, rails and catenary. These data further confirm that it is the moving parts of the train that are producing most of the metalliferous FePM so typical of the subway environment.

3) During the IMPROVE monitoring campaigns the opportunity arose to test a "state-of-the-art" **air purifier** currently in its research and development phase. The purifier comprises a set of six commercial air recirculation/filtration units equipped with a glass microfiber filter for particles with a diameter > 0.2µm and a glass microfiber HEPA filter, with a supposed > 99.9% efficiency for particles with a diameter between 0.1 and 0.3µm. The best result in terms of air quality improvement occurred during operational hours when $PM_{2.5}$ mass concentrations at the end of the platform fell by over 30% (61 vs 88µg/m^3) when the purifier was placed close to the measuring equipment. The effectiveness of the purifier can also be demonstrated by measuring particle number concentrations, as revealed in the graphic below (Figure 11).

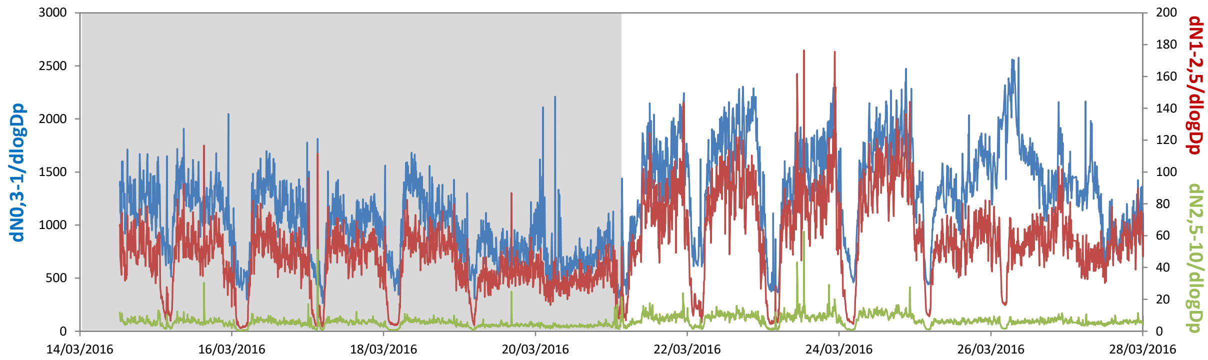


Figure 11. Time series of particle number concentrations at Tarragona subway station, with purifier adjacent to measuring equipment. Note the reduction in all PM size ranges (grey area with purifier on).

However, this benefit was limited in spatial extent: when the measuring equipment was placed in mid-platform, away from the purifier, a much lower (10%) improvement in air quality was seen. Thus, air purifiers have the potential to improve subway platform air quality, but they need to be sufficiently powerful or numerous to make a substantial difference that would justify the extra expenditure on equipment and energy. The air purifier did not preferentially fractionate particles, with crustal, carbonaceous and ferruginous PM being trapped equally. Given the dominance of the ferruginous "subway metal" component in platform air, air purifiers designed to focus more on removing this metallic fraction underground have the potential for greater success compared to those unable to fractionate different chemical components.

4) The most obvious example of how subway FePM levels can be greatly reduced is provided by the brand new L9S Collblanc station which is equipped with **platform screen doors (PSD)** and powerful modern ventilation systems. On this station platform $FePM_{2.5}$ levels are ten times less than measured on Tetuan station, which has a similar design but is old and lacks PSD. It is therefore clear that in some stations the application of appropriate mitigation measures has the potential to reduce ambient levels of platform FePMµg/m^3 by several tens of micrograms. The PSD system however must be full length; otherwise any air quality benefit is likely to be minimal or zero. It is also the case that even with PSDs in place, air quality is likely to deteriorate without powerful tunnel ventilation systems that serve to extract FeCPM that are prevented from escaping via the station platform.

Delays due to mechanical failure of the heavy equipment used to lay track ballast, and an over-tight schedule to complete all monitoring in September 2016, forced adjustments to originally proposed deadline dates. These adjustments were discussed with the LIFE Monitoring Team from NEEMO EEIG (June 2016), and it was agreed to shift forward deadlines for ending all activities for this action by June 2017. In addition to the four technical progress reports previously shown in Annex VI, the following reports have been produced in this B2 action:

- *Annex VIII: Effects of ballast addition on passenger exposure.*
- *Annex IX: Effect of ventilation modes in air quality at a subway platform (Tarragona, L3).*
- *Annex X: Impact of mechanical ventilation on air quality: Collblanc (L9S).*

A report on PM contributors and potential mitigation measures by MC. Minguillón and T. Moreno (CSIC) is given in Deliverable 9, and a Technical Guide to improve air quality in the subway system written by T. Moreno (CSIC) in Deliverable 10. The latter has been sent to

Table 8. Summary progress of Action B2

		2014	2015				2016				2017				2018
Action		IV	I	II	III	IV	I	II	III	IV	I	II	III	IV	I
B2	Foreseen				■	■	■	■	■						
	Actual				■	■	■	■	■	■	■	■			

Deliverable		Deadline		Status
		Project	Solicited	
9	Report of mitigation measures in subway systems	30/09/2016	30/03/2017	Completed
10	Technical guide for mitigation measures	30/09/2016	30/06/2017	Completed
Indicators of implementation				
Testing of mitigation measures				Achieved
Technical Guidance concerning the experiments applied to reduce tunnel dust resuspension				Achieved
Technical Guidance which will specifically identify and compare effective strategies for reducing the impact of each of the selected emission sources.				Achieved

Continuation after LIFE: This action will not continue after the project end date. The results from this action will be the main legacy of the IMPROVE LIFE project and will be used after the finalisation of the project for subway authorities, supplying technical guidance documents for present and future subway networks with a better air quality. The methodology and deliverables from this action will be used to aid the development of appropriate protocols designed to improve air quality in other forms of urban transport, such as the newly awarded BUSAIR project, which again involves collaboration between TMB in Barcelona and CSIC (T. Moreno). This project, aimed at the study of bus emissions, will last from 01/2017-12/2019, and is financed by the Spanish Government (CGL2016-79132-R-BUSAIR, 128.000€).

5.1.4 Action C1 Effectiveness of the project actions

This action focuses on the evaluation of the policy effectiveness of the project's actions, but following the requirement from the European Commission (letter 22/07/2016) the action now also includes the evaluation and monitoring of the project impact (see the introductory document included in this report answering technical and administrative requirements made in EC letters). During the lifetime of the project the evolution of the PM concentrations and the impact of the main emission sources in the subway systems were registered. The project management team set up specific **indicators** to be used to measure the impact of the project against the initial situation, which has been assessed in the case of the Barcelona subway system during the implementation Action B1. These indicators included:

- The *initial situation* regarding PM levels and sources that has been documented during Action A1 (Annex XI_C1_Initial Situation) by C. Reche from CSIC.
- The *contribution of selected parameters* in the PM levels and compositions (Deliverable 13. Minguillón et al. Submitted). A total of ten different sources were identified and quantified (Figure 12). Five sources are subway-specific, four have a clear outdoor origin, and one of them might be originating from both indoors and/or outdoors. The outdoor sources are: urban (reflecting the urban cocktail including road traffic and industry), fuel oil (attributed to shipping emissions), sulfate (secondary pollutant), and sea salt. The contribution of these sources ranged from 6% to 55% of bulk $PM_{2.5}$. The subway sources are: a rail source; two types of brakes (A and B); a source resulting from a mixture of rail abrasion emissions and brakes emissions (Rail+Brake); and a Pb source. The source identified as Soil can be both of indoor origin (from the abrasion of ballast) and outdoor origin, nevertheless no clear relation has been found between the contribution of this source with the presence or absence of ballast.

  The contribution of the different subway sources depends directly on the frequency of trains and passenger influx. The influence of rail and wheels abrasion is observed in all stations and seasons, with the exception of Joanic station in the warm season. A brake specific source was identified for L1 and L3, both using a similar combination of brake types, and accounted for 15% to 35% of bulk $PM_{2.5}$. A second brake specific source was identified for L4 (36% to 52% of $PM_{2.5}$), and in a lower proportion for L2 and L10 (4-14% of $PM_{2.5}$). Due to existing co-emissions, a source influenced by rails and wheels abrasion and brakes abrasion was identified with a non-negligible contribution for any station. A specific source characterized by high Pb content was identified only in Sagrera station and therefore is considered specific of this station.

  For a given station, the brake-related sources accounted for a higher percentage than the rail and wheel related sources. Thus, to improve the air quality in the subway environment, the focus should be rather on the brakes than on other components. Fe, the main component of $PM_{2.5}$ in the subway environment is attributed (>70%) to the rail and wheels abrasion. Total Carbon is apportioned by a variety of sources, i.e. brakes, Pb source, Fuel oil source and an Urban source, reflecting the influence of surface road traffic emissions on subway platforms.
- The *effect of reducing emissions of specific factors* monitored during Action B2. This effect is discussed in Deliverable 10 which has been published as a technical guide. Key points are brought together in an overview of measures most likely to achieve notable improvement in subway air quality, along with a tabulated consideration of the associated benefits and

drawbacks for each measure. Five hundred copies have been printed and are being distributed to stakeholders including all subway systems worldwide.

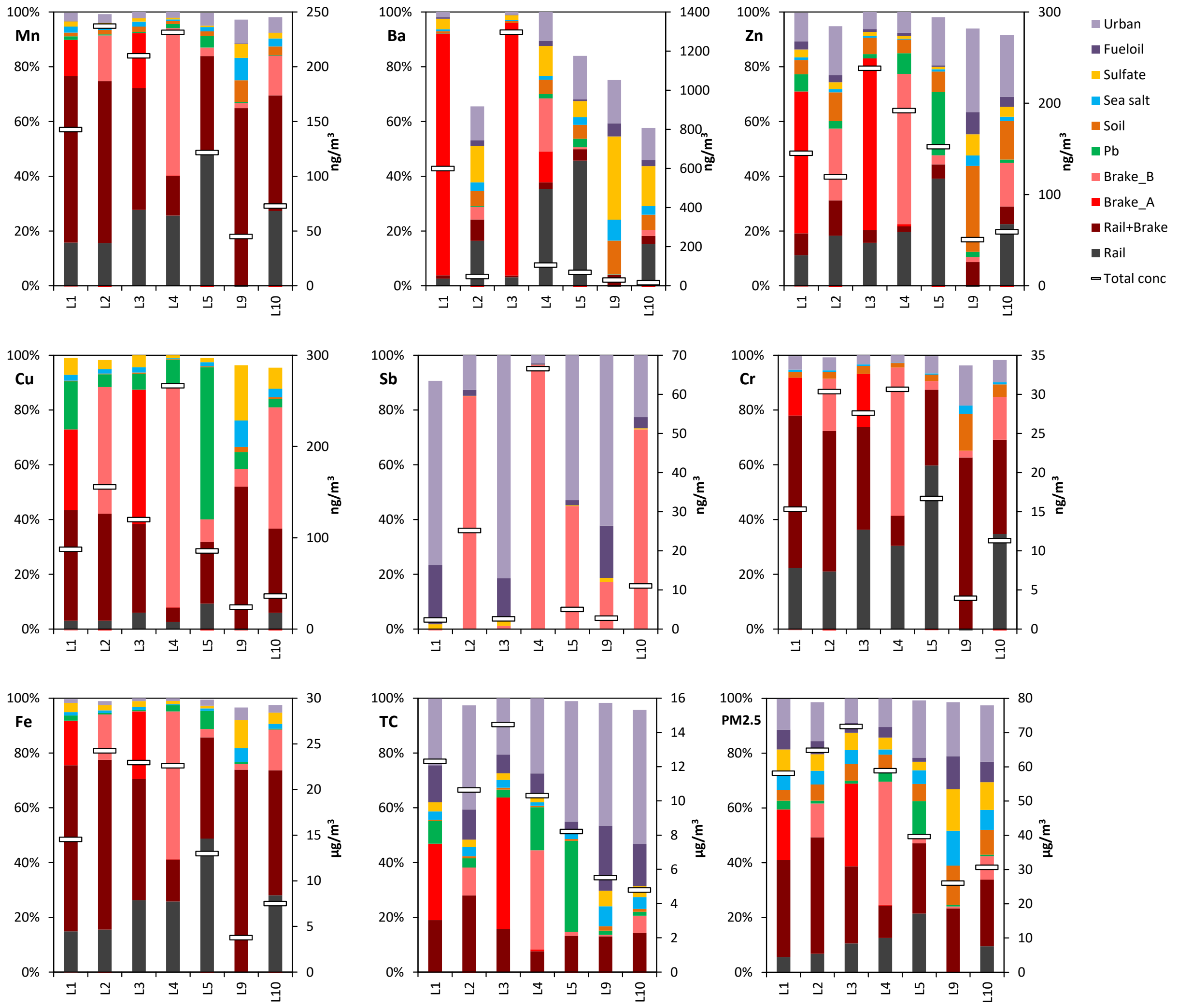


Figure 12. Average relative source contribution for selected elements for the different subway lines measured in Barcelona subway system during IMPROVE.

An **external committee** to evaluate the progress and impact of the project was nominated, formed by five international air pollution experts including: *Prof. G. Buonanno* (Univ. of Cassino, Italy), *Dr. C. Duchaine* (Univ. Laval, Canada), *Dr. A. Giretti* (Univ. Politecnica delle Marche, Italy), *Prof. F. Kelly* (King's College London, UK); and *Prof. L. Morawska* (Queensland Univ. of Technology, Australia). Their comments are included in Deliverable 12. Since the beginning of the project significant replication efforts have taken place, as the aim of the project is to present pollution mitigation measurements applicable to all subway systems. Thus a strict protocol was established for all measurements, with monitoring campaigns being carried out a minimum of twice, and at different times of the year, and with monitoring equipments being located in the same location at all times, to minimise the influence of other parameters in the analysis.

Using IMPROVE methodology and dissemination, any subway institution now has access to clear guidelines as to how to characterise the spatial and temporal variability of particulate matter, and determine the sources and their impact on the air quality of the station platform. The report on policy-effectiveness is given Deliverable 12: Report on the evaluation of **policy effectiveness** and monitoring of the impact of the project.

Table 9. Summary progress of Action C1

		2014	2015				2016				2017				2018
Action		IV	I	II	III	IV	I	II	III	IV	I	II	III	IV	I
C1	Foreseen														
	Actual														

Deliverable		Deadline	Status
12	Report on the evaluation of policy effectiveness and monitoring of the impact of the project *(Title and content modified according to the suggestion from EC letter 22/07/2016)*	31/12/2017	Completed
Indicators of implementation			
Set the indicators to assess the impact of the project			Achieved
External committee nominated			Achieved
Three-months summary reviews			Achieved
Quality plan of the effectiveness of the project			Achieved

Continuation after LIFE: The impact of the actions of the IMPROVE LIFE project will be monitored in future years, especially concentrating on campaigns being made in stations where our protocols have been applied. TMB and CSIC have a history of cooperation working on air quality before this project and, greatly strengthened by IMPROVE, this will continue after it is finished.

5.1.5 Action C2 Assessment of the socio-economic impact of the project

This Action started on June 2016. The main results are given below:

• Two differently designed **questionnaires** were utilised during the project in order to evaluate public perception of Air Quality in underground subways. One of the questionnaires was performed by Transports Metropolitans de Barcelona (TMB) and was aimed specifically at subway users in Barcelona, through personal interviews in the subway facilities. The second one was publicized through the webpage of the project (http://improve-life.eu/) in English and Spanish and from the project participants to their social networks. Volunteers had to complete it through an online application available in the webpage of the project. (Deliverable 11 Questionnaires for subway users). More than 50% of total participants thought that the state of air quality at the subway facilities is poor, while 38% perceive it as ok or acceptable. Only 7% consider that the state can be classified as good. The analysis of this perception by the city of residence/work indicates that in the city of Barcelona almost 70% of respondents think that the state of air quality is poor.

On the other hand, respondents mostly think that air is cleaner inside the train (63%, compared to the state of the air on the platform. This perception has been confirmed as fact by a number of scientific reports on Barcelona subway air quality, which associate this observation with the presence of air conditioning systems inside trains and with the sealing of trains' windows. The vast majority of survey participants think that air quality at subway facilities could be improved (88%). This percentage of respondents was also asked about possible measures to improve air quality, but few of them were able to suggest an answer, although most of those who did respond proposed more than one measure. All responses are shown in Deliverable 11.

• The coordinating beneficiary conducted a study to estimate the socio-economic impact of the project, including a cost-benefit analysis shown in Deliverable 20: Report on socio-economic impact. IMPROVE main impacts are related to:

Health. Good air quality improves the public health by reducing the population's exposure to air pollutants, thus health problems caused by air pollution will be reduced and consequently there will be fewer admissions to hospitals. Direct costs related to respiratory and/or cardiovascular problems (medicine, physician, medical tests and hospitalization) and indirect costs (loss of wages due to illness) will be reduced as lifestyle and public health improve. Although in the limited lifetime of the IMPROVE LIFE project it is difficult to evaluate precisely the benefits concerning health, given what we already know about the effects of inhalable PM on human well-being, there is no doubt that a reduction of ambient PM in subways will improve commuter health.

Policy effectiveness. The project has generated the largest open access scientific database in the world on air quality in subway platforms and trains, and has used this to focus on what changes can and should be done to improve matters. The IMPROVE LIFE project has also provided knowledge and advice to subway air quality managers, enabling and encouraging them to recognise the problem and consider cost-effective air quality measures for decreasing air pollutant concentrations. We have emphasised that although at present there is no official regulation on air quality in such environment, such regulatory control is likely to be applied in the future.

Air pollution management. The meticulous source apportionment study carried out over 500 chemical analyses of $PM_{2.5}$ and their source materials was crucial to calculate the contribution of each air pollutant source characteristic of the subway system. This helped to categorise the major problems and the effectiveness of best practice measures that could be used for air pollution abatement. The collaboration between the IMPROVE LIFE partners provided an added value to the project outcomes and lead to recommendations to subway air quality managers elsewhere in Europe regarding the adjustment of best practices used.

Replication, transferability, cooperation. Since the beginning of the project significant replication efforts have been made, as the aim of the project is to present pollution mitigation measurements applicable to all subway systems worldwide. Using IMPROVE methodology and dissemination, any subway operator worldwide now has full access to clear guidelines as to how to determine the sources and their likely impact on the air quality of the station platform. Various meetings with stakeholders to present and discuss IMPROVE LIFE results have been carried out, including: Metros of Bilbao, Valencia, Sevilla and Madrid, Renfe (Spanish National Railway Network), Barcelona City Hall, Adif (owner of Spanish rail infrastructure), Transport for London, Vienna Subway (U-Bahn), and the International Association of Public Transport (UITP, Rotterdam). In all meetings the IMPROVE technical guide for improving air quality in the subways systems was presented as a keynote reference publication to which all future mitigation actions should be referred.

Employment. The adoption and implementation of measures to improve air quality should boost local employment as companies and industries involved will need to attract and retain skilled staff. New business and employment opportunities in the area of improving air quality in the subway system during the project and after its finalisation include: the marketing of nanopolymers to mitigate dust resuspension, the manufacture and installation of platform screen door systems in subway platforms, innovation by mechanical/electrician workers to plan and control (flow direction and intensity) the best ventilation protocol for both tunnel and platforms.

Public awareness. The implementation of the public awareness activities also has an important indirect socio-economic impact on different target groups and stakeholders. The importance of all the project actions and their effect on understanding subway air quality have been communicated in diverse ways (leaflets, presentations to institutions, interviews in tv and radio, mass media releases etc.).

No major problems have been found within this action, and progress was made according to the original proposed plan (Table 10).

Table 10. Summary progress of Action C2

		2014	2015				2016				2017				2018
Action		IV	I	II	III	IV	I	II	III	IV	I	II	III	IV	I
C2	Foreseen														
	Actual														

Deliverable		Deadline	Status
11	Questionnaires for the public and stakeholders	31/12/2016	Completed
20	Report on socio-economic impact	31/03/2018	Completed
Indicators of implementation			
Responses from the general public to the questionnaire			Achieved

Continuation after LIFE: Similarly to Action C1, the impact of the actions of the IMPROVE LIFE project will be monitored in future years, especially concentrating on campaigns being made in stations where our protocols have been applied. TMB and CSIC have a history of cooperation working on air quality before this project and, greatly strengthened by IMPROVE, this will continue after it is finished.

5.1.6 Action E3 Networking with other projects

IMPROVE LIFE started collaborations and/or presented results to:

i) LIFE13ENV/IT/000140 DIGITALIFE. 4/06/2015, T. Moreno presented *Proyecto LIFE-IMPROVE Air quality in rail subway system*.

ii) LIFE11ENV/ES/000584 AIRUSE. 19/04/2016 T. Moreno presented *IMPROVE LIFE+: Measures to improve air quality in the subway system*.

iii) Visit of representatives of the Department of Environmental Development Policy (Ms Terez Krisztina Szabo) of the Ministry of Rural Development from the Hungary Government (13/05/2016). The purpose of this visit was to know how the proposal of the IMPROVE project was prepared and how the project is producing results.

iv) LIFE13 ENV/ES/000417-B1 RESPIRA LIFE. 12/12/2017. T. Moreno gave a presentation on IMPROVE LIFE results during the Final Conference of the project.

v) The attendance of T. Moreno (who presented IMPROVE results) to the 21st European Forum on Eco-innovation event in Sofia in February 2018 allowed the discussion with many other European (including LIFE) projects, such as GrowSmarter, Smart Clean City Air, LIFE PREPAIR, CleanOx for Cleaner Air, CLEAN HEAT, Brenner Lower Emission Corridor (LIFE), LIFE GYSTRA, LIFE FOR SILVER COAST, LIFE N Grab HY and ICARUS.

A successful **Open Expert Workshop** on air quality in subway systems was hosted by IMPROVE LIFE on 07/05/2015 in Barcelona. The event was open to researchers, stakeholders, public/private organisations and the general public. Stakeholders from the local City Council, Government of Catalonia, Local Public Health Agency and Ferrocarrils de la Generalitat attended the event. Oral presentations included not only studies within IMPROVE LIFE (Martins, Minguillón, van Drooge), but also from Veillette (Univ. Laval, Canada), Múgica (Univ. Azapotzalco, Mexico), García (Ingenieros Asesores SA), Blondeau (Uni. La Rochelle, France) and Kelly (Kings Coll., UK).

An **Air Quality Platform Meeting** was hold in Barcelona on 26-27th of September 2017, to which other LIFE projects were invited. This event was related to the one-day workshop with other European Projects initially scheduled to take place before 30th of June 2015 but postponed for later when the results of IMPROVE LIFE were further advanced. The 2-day workshop was hosted by the IMPROVE and AIRUSE (LIFE11/ENV/ES/584) projects as a LIFE Platform Meeting under the title "Abating urban exposure to air pollutants" and had the following agenda:

Tuesday 26/09/2017

09:00 h: Registration

09:20-09:45 h: Welcome to delegates by **Mercè Rius** (General Director, D.G. Environment, Government of Catalonia), **Janet Sanz** (Vice-Mayor of Barcelona), **Xavier Querol, Teresa Moreno,** (PIs of AIRUSE and IMPROVE LIFE+ projects, respectively)

09:45-10:00 h: Presentation of LIFE ENV PROGRAME by **Mario Lionetti,** from EC-EASME

10:00-11:20 h: Introduction: Challenges and problems to overcome at four scales

· The view of the Regional Governments, by **Mercè Rius,** from D.G. Environment, Government of Catalonia
· A European overview, by **Alberto González Ortiz,** from Euro pean Environmental Agency
· The view of the State Members, by **Irene Olivares,** from D.G. Environment, Spanish Ministry of Agriculture, Food, Fishing and Environment
· The view of the cities, by **Joan Marc Craviotto,** from Barcelona City Council

11:20-11:50 h: Coffee break

11:50-13:10 h: Effectiveness of urban air quality measures (projects)

· AIRUSE, Sources and measures_1 (LIFE 11 ENV/ES/000584). **Xavier Querol**
· AIRUSE, Sources and measures_2 (LIFE 11 ENV/ES/000584). **Fulvio Amato**
· REDUST-LIFE (LIFE 09 ENV/FI/000579). **Outi Väkevä**
· LIFE COBRA (LIFE 13 ENV/IT/000492). **Andrea Bonfanti**

13:10-14:10 h: Lunch break

14:10-15:30 h: Effectiveness of urban air quality measures (projects)

· E-MOBILITY-LIFE (LIFE11 ENV/NL/000793). **Pieter Looijestijn**
· AUTO LIFE12 ENV/FR/000480. **Thierry Seguelong**
· MINOx-STREET-LIFE (LIFE 12 ENV/ES/000280). **Magdalena Palacios**
· CLEAN HEAT-LIFE (LIFE14 GIE/DE/000490). **Laura Krug**

15:30-16:10 h: Effectiveness of urban air quality measures (the cities)

· London. **David Dajnak,** from King's College London
· Madrid. **Angeles Cristobal,** from Madrid City Council

16:10-16:30 h: The Air-Alliance: European vehicle eco-labelling for new and old vehicles. **Nick Molden and Massimo Fedeli**

16:30-17:00 h: Coffee break

17:00-18:00 h: General debate

18:00 h: End of the session

IMPROVE AIRUSE

Wednesday 27/09/2017

09:00-09:15 h: AXA research fund guidebook on AIRUSE LIFE+ measures to improve air quality. **Fulvio Amato**

09:15-09:30 h: European Investment Project Portal (EIPP). **Ramona Ocak,** from EC- DG ECFIN

09:30-10:30 h: Citizen exposure while commuting

- IMPROVE Subway air quality measures (LIFE13/ENV/ES/000263). **Teresa Moreno**
- IMPROVE Subway exposure to organic compounds (LIFE 13/ENV/ES/000263). **Barend van Drooge**
- RESPIRA-LIFE-Urban Cycling (LIFE 13/ENV/ES/000417). **Jesús M. Santamaría**

10:30-11:00 h: Coffee break

11:00-12:00 h: Citizen exposure while commuting (continuation)

- LIFE GYM. (LIFE14 ENV/GR/000611). **Georgios Saharidis**
- PASTA (FP7/ 602624-2). **Luc Int Panis**
- The case of the Greater Paris Area. **Sophie Moukhtar,** from AIRPARIF

12:00-12:40 h: Clean public transport

- TMB – Metropolitan Transports of Barcelona. **Josep Armengol**
- SLIDE IN-LIFE+ (LIFE 10/ENV/SE/00035). **Patrik Rydén**

12:40-13:20 h: Models and tools for air quality management

- GySTRA (LIFE 16/ENV/ES/00082). **Dolores Hidalgo**
- Supporting implementation of the Air Quality Plan for Malapolska (LIFE IPE PL 021). **Lisa Blyth**

13:20-14:20 h: Lunch break

14:20-15:20 h: Models and tools for air quality management (continuation)

- LONDON HYBRID EXPOSURE MODEL. **David Dajnak**
- BrennerLEC (LIFE 15/ENV/IT/000281). **Laura Pretto**
- LIFE-IP PREPAIR (LIFE 15/IP/IT/000013). **Lavinia Laiti**

15:20-16:20 h: General debate

16:30 h: End of the meeting

26-27 September 2017
EL BORN CENTRE
Plaza Comercial 12
BARCELONA, SPAIN

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AIR 

Main results of both the Open Expert Workshop and the Air Quality Platform Meeting are shown in Deliverable 6: Minutes of expert workshop.

Annex XII: Networking with other projects contains all the photographic material concerning the aforementioned networking activities.

Table 11. Summary progress of Action E3

		2014	2015				2016				2017				2018
Action		IV	I	II	III	IV	I	II	III	IV	I	II	III	IV	I
E3	Foreseen														
	Actual														

Deliverable		Deadline	Status
6	Minutes of the expert´s workshop	30/09/2015	Completed
Indicators of implementation			
Number of people attending IMPROVE meetings			Achieved

Continuation after LIFE: This action will continue to be active after the project is finished as contact and collaboration with both other subway systems and other LIFE projects will be achieved during future presentations of results, the sharing of guidance documents and other information sources, as well as collaboration regarding future funded projects, especially for example in the application of IMPROVE results to other worldwide subways.

5.1.7 Action E4 After-LIFE+ Communication Plan

The After-LIFE+ Communication Plan was prepared in English and Spanish and is shown in Deliverable 14. The plan aspires to ensure the sustainability of the project outcome and further promote its objectives. Its main aspects are:

- The project **website** including key strategies and experience gained through IMPROVE LIFE project. The website will be operating until 2023.
- The close operational relationship developed between the **IMPROVE members** (CSIC and TMB) will continue in the future, for example working together through the project´s website and on future projects, as demonstrated by the ongoing recently funded BUSAIR project (2017-2020) designed to investigate the air quality inside public buses.
- Meetings with **stakeholders** from other international subway systems for the continuous update of mitigation measures and strategies. This will assure the continuous involvement of stakeholders in the policy context of the project.
- Activities to raise **public awareness** and engagement will be taken up as science communication events and festivals – open days at institutions to inform the public of the science which are conducted in their local area for example.
- Additional publications of IMPROVE LIFE findings will appear in **peer reviewed journals**, using open access journals wherever possible.
- The IMPROVE LIFE results and recommendations will continue to be presented at **conferences, workshops and symposia** during the course of the upcoming years. On the 24th May 2018 T. Moreno has been invited to present IMPROVE results in Madrid to the 23rd meeting for COMITÉS TÉCNICOS DE ALAMYS (*Asociacion Latinoamericana de Metros y Subterraneos)*.
- These results will be available and explained to any third party that requests it (both via the website and on request to the project coordinator).

Sources of funding to cover the costs of these activities include current and future research projects (i.e. ACS and BUSAIR Spanish funded projects) and internal resources from permanent CSIC staff members.

This action was programmed to start on July 2016, but it was proposed to be put forward to January 2017. This modification was approved by the European Commission in its letter from 22/07/2017.

Table 12. Summary progress of Action E4

		2014	2015				2016				2017				2018
Action		IV	I	II	III	IV	I	II	III	IV	I	II	III	IV	I
E4	Foreseen														
	Actual														

Deliverable		Deadline	Status
14	After-Life Communication Plan	31/03/2018	Completed

5.2 Dissemination actions

5.2.1 Objectives

The **scope** of these actions is to convey the project results as much as possible, raising awareness towards improving air quality in the subway system. Activities have been developed addressing 3 different target groups:

(1) Attracting interest from media communication services both locally in Spain and worldwide,

(2) Government organisations and transport authorities responsible for the healthy and energetically efficient operation of city subway systems,

(3) The urban population in general, but most specifically the train passengers and workers.

Important communication **activities** of IMPROVE LIFE results included:

- The development of the project website (Action D1).
- Display of information boards (Action D2).
- An Open Forum with stakeholders and the organization of an International Conference (Action D3).
- The production and distribution of an informative pamphlet describing the project scope and objectives, the expected results and the likely benefits to be derived from their application (Action D3).
- The preparation of articles for the local and national press during the project (Action D3).
- The production and distribution of a technical guide with measures to reduce air pollution in the subway system (Action B2).
- Technical publications on the project results in international scientific journals and presentations in scientific conferences acknowledging the LIFE+ community financial support (Action D3).
- The dissemination of a Layman's Report (Action D4).
- Meetings with other subway systems (Transport for London, Metro Málaga, Metro Bilbao, Metro Valencia, Metro Sevilla, Metro Madrid, Vienna Metro) and stakeholders (Barcelona City Council, Renfe, Adif), the International Association of Public Transport (UITP), and the Association of Iberoamerican subway systems (Alaymis) (see annex XIX).

Further dissemination activities are:

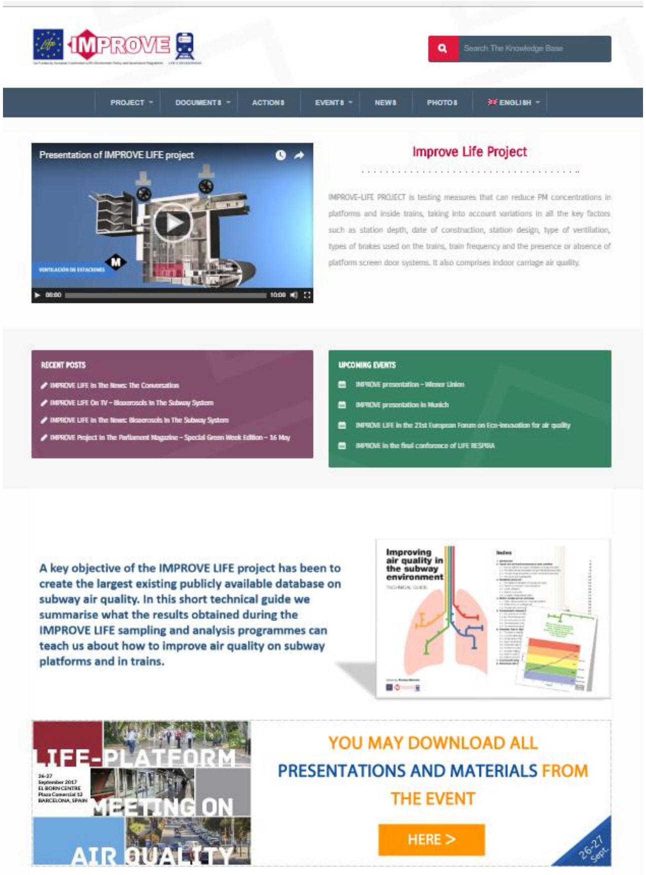
- The dissemination of IMPROVE results via Newsletter of the EU-COM (Action D3).
- The dissemination of IMPROVE results via the website of the Life community: http://www.lifecommunity.eu/ (Action D3)

5.2.2 Dissemination: overview per activity

ACTION D1 *A Project website*

The web site of IMPROVE (http://improve-life.eu) was launched in December 2014 and is updated on a 2-week basis. Its contents are in both Spanish and English and introduce the project, describing its participants, objectives, activities and results. Through this web address all the results achieved so far as well as dissemination material such as presentations, reports, informative documents are made freely available to the public, as well as the public events organised. A page listing all delivered materials (publications, deliverables) is also included.

The agenda with all events and activities can be found, permanently updated. A section for the "Life-platform meeting" has been introduced at the website main page, as well as the Technical Guide produced describing how to improve air quality in subway systems (that can be downloaded). The IMPROVE video is also featured at the entrance page.



The IMPROVE web page (Deliverable 1) has had so far an average number of 1,000 visits per month, a number much greater than the minimum target of 7,000 hits per year aimed in the proposal, with each visitor looking on average 8 sections of the webpage.

No problems have been reported in this Action (Table 13).

Table 13. Summary progress of Action D1

		2014	2015				2016				2017				2018
Action		IV	I	II	III	IV	I	II	III	IV	I	II	III	IV	I
D1	Foreseen														
	Actual														

Deliverable		Deadline	Status
1	Project website	31/12/2014	Completed
Indicators of implementation			
Design and maintenance and updating of the project website			Achieved

Continuation after LIFE: The web page of the project will be maintained and continue to be visited after the project is finished, allowing citizens, stakeholders and those using and studying other subway systems to see all reports, including the Layman's Report.

***ACTION D2** LIFE+ Information boards*

IMPROVE LIFE+ Information boards (Deliverable 3) have been on display since January 2015 describing the project at the locations where it is implemented, at strategic places accessible and visible to the public. In addition, vinyl sticky boards have been located in the platforms of Sagrera, Palau Reial, Maria Cristina, Tarragona, Santa Coloma, Joanic, Saint Ildefons, Collblanc and Poble Sec stations where measurements have been performed. Hard information panels are also permanently displayed in IDAEA-CSIC (Palau Reial) and TMB (Santa Eulalia) main offices.

During the whole time that these panels have been on display only once has the panel located on a station platform needed to be changed due to graffiti. As vandalism was considered possible during the length of the project, replacement information boards were already immediately available for the required renewal. The panels have stayed on display until the end of the project.

No problems have been reported in this Action (Table 14).

Table 14. Summary progress of Action D2

		2014	2015				2016				2017				2018
Action		IV	I	II	III	IV	I	II	III	IV	I	II	III	IV	I
D2	Foreseen														
	Actual														

Deliverable		Deadline	Status
3	Information boards	31/01/2015	Completed
Indicators of implementation			
Information boards placed on monitoring locations and partners offices			Achieved

ACTION D3 *Dissemination of project results including a Networking-Open forum with key stakeholders*

All articles and press releases are available in *Deliverable 15**: Articles in the general and trade press and also at IMPROVE LIFE website* *http://improve-life.eu/en/categoria/news/**. Below are presented some examples of the information reported in this action* (Annex XIV)*.*

The following activities have been performed to disseminate the project results:

i) The launching of the measuring campaigns regarding air quality in Barcelona´s metro environment was widely announced in the **local and national media**, including:

- 43 Digital press news (Btv.cat, Efeverde, Radiointereconomia.com, El Periódico De Catalunya, Elconfidencial.com, Negocios.com, Eleconomista.es, Europa Press, Gente Digital, Horapunta.Tmb.cat, Presspeople.com, Teinteresa.es, Nació Digital, Vialibre-Ffe.com, Corresponsables.com, Obrasurbanas.es, Compromisorse.com, Esmartcity.es, etc.),
- 8 news in local/national Newspapers (ABC, Diario Barcelona, El Dia, La Vanguardia, El Punt Avui, 20 Minutos Barcelona, El Periodico),


Cosas de la vida | GRAN BARCELONA
La calidad ambiental del suburbano

¿Qué respiramos en el metro?

Un análisis detecta micropartículas en suspensión procedentes del desgaste de los railes y los frenos

También se observan trazas de nicotina, cremas, sal y humo del exterior, pero no en gran cantidad

Gran Barcelona

Bendita mampara

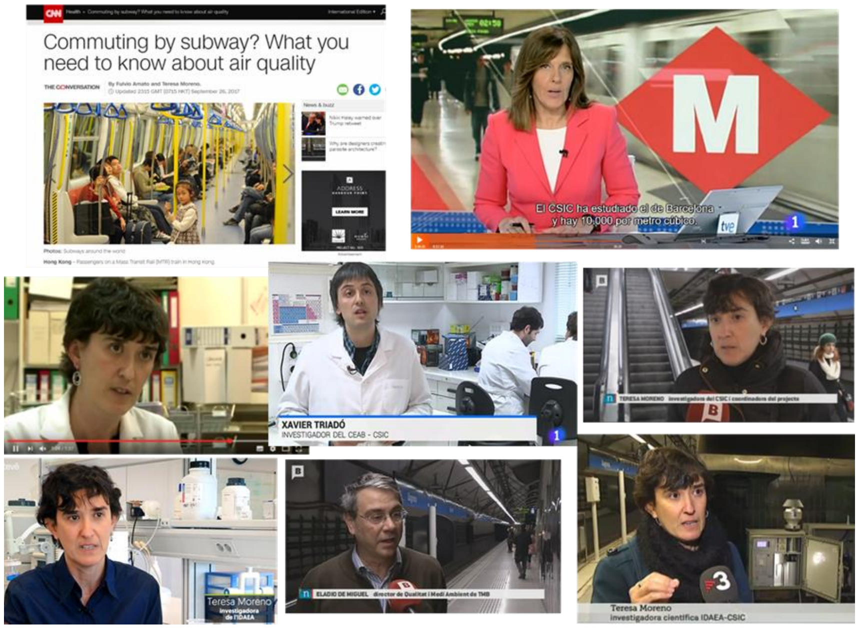
Las estaciones de la L-9 y la L-10 con separación entre el andén y la vía tienen la menor densidad de contaminantes de todo el metro

Los vagones tienen un aire excelente porque los filtros de refrigeración absorben partículas

La contaminación aumenta en las horas punta debido al mayor trasiego de trenes y viajeros

Un proyecto sufragado por la UE busca alternativas de mejora. Lo coordinan el CSIC y TMB

- 7 interviews on local/national news and scientific Radio programmes (Cadena Ser Catalunya El Balco, Rac 1 El Mon, Cadena Ser Catalunya Hoy Por Hoy Catalunya, Radio 4, Radio Nacional España R1)
- 5 appearances in Television news (BTV Noticies Migdia, BTV Noticies Vespre, TV3 Tn Comarques, RTVE Telediario, 8TV news)
- Internal TV in subway system: MouTV, with 20 second adverts shown several times per week at monitors both inside all trains and on platforms.



ii) Two **informative videos**, lasting 10 minutes (shown in the web page) and 20 minutes (shared with other subway systems) explaining the aims of the IMPROVE LIFE project are in preparation. The script has been translated into three languages (English, Spanish and Catalan). Annex XV.

iii) Production of an **informative pamphlet** (Deliverable 7) with the aims of the project in 3 languages (English, Spanish and Catalan) distributed to assistants to the Open forum event.

iv) Presentation of the project in the **Feria del Studiant** for the Saló de l'Ensenyament, 18-22 March 2015. The Salo de l'Ensenyament held in the framework of the Week of Training and Work of Fira de Barcelona is one of the biggest events in Barcelona attracting over 250 Exhibitors (http://www.fundaciorecerca.cat/ca/projecte_detall.asp?id_projecte=1187).

v) Organisation of an **Expert's Workshop Special Session on "Commuter air quality in rail subway systems"** (06/05/2015, Deliverable 6) within the SETAC Europe 25th Annual Meeting (http://barcelona.setac.eu/).

vi) Celebration of the **Open Forum on air quality in subway systems** (07/05/2015, Deliverable 5) in the CSIC central offices in Barcelona. The event was open to researchers, stakeholders, public/private organisations and the public in general. Stakeholders from the local City Council, Autonomous Government of Catalonia, Barcelona Public Health Agency and Ferrocarrils de la Generalitat attended the event. The Open Day continued with a field visit to the currently operating IMPROVE LIFE sampling site in Palau Reial station, and the nearby air pollution monitoring urban background site in IDAEA operated jointly by CSIC and Generalitat de Catalunya. The celebration of the Openday was shown in the internal TV channel of the Barcelona metro (MouTV).

vii) Celebration of an **international conference** organised by IMPROVE on 3-6th of July 2017 in Barcelona (http://www.ricta2017.org/), where IMPROVE results were presented, with the participation of about 120 participants including researchers, and national, regional and European stakeholders. The agenda of the meeting is shown in Annex XVII.

viii) Organisation of an **Air Quality Platform Meeting** held in Barcelona on 26-27th of September 2017, to which other LIFE projects were invited. The 2-days workshop was hosted by the IMPROVE and AIRUSE (LIFE11/ENV/ES/584) projects as a LIFE Platform Meeting under the title "Abating urban exposure to air pollutants" (Annex XVIII).

ix) Technical publications (Deliverable 13) on the project results in international scientific journals and presentations in scientific conferences all fully acknowledging the LIFE+ community financial support. Although a minimum number of six such publications was promised in the initial project proposal, the high level of interest in subway air quality and the large amount of data amassed by IMPROVE LIFE so far has enabled us already to publish sixteen papers in international (SCI) journals, as listed below:

16 Scientific international publications

Martins, V., Minguillón, M.C., Moreno, T., (...), Centelles, S. & Lazaridis, M. (2015). Deposition of aerosol particles from a subway microenvironment in the human respiratory tract. J. of Aerosol Sci., 90, 103–113.

Martins, V., Moreno, T., Mendes, L., (...), Querol, X. & Minguillón, MC. (2016). Factors controlling air quality in different European subway systems. Environ. Res., 146, 35–46.

Martins, V., Moreno, T., Minguillón, M.C., (...), Centelles, S. & Querol, X. (2016). Origin of inorganic and organic components of PM2.5 in subway stations of Barcelona, Spain. Environ. Pol., 208, 125–136.

Martins, V., Moreno, T., Minguillón, MC., (...), Capdevila, M. & Querol, X. (2015). Exposure to airborne particulate matter in the subway system. Sci. Tot. Environ., 511, 711–722.

Minguillón, MC., Reche, C., Martins, V., Capdevila, M., de Miguel, E., Querol, X. & Moreno, T. Main particle sources in underground rail systems. Submitted to journal.

Moreno, T., de Miguel, E. (2018). Improving air quality in subway systems: An overview. Environ. Pol. In press.

Moreno, T., Kelly, F., Dunster, C., Oliete, A., Martins, V., Reche, C., Minguillón, MC., Amato, F., Capdevila, M., de Miguel, E. & Querol, X. (2017). Oxidative potential of subway PM2.5. Atmospheric Environment, 148, 230-238

Moreno, T. Martins, V. MC. Minguillón, (...), Centelles, S. & X. Querol. (2015). Key factors influencing air quality in rail subway systems. Journal of Transport & Health, 2, S57.

Moreno, T., Martins, V., Querol, X., (...), Centelles, S. & Gibbons, W. (2015). A new look at inhalable metalliferous airborne particles on rail subway platforms. Sci. Tot. Environ., 505, 367–375.

Moreno, T., Querol, X. Martins, V. (...), Eun, HR. Ahn, K. Capdevila M. & de Miguel E. (2017). Formation and alteration of airborne particles in the subway environment. Environ. Sci.: Processes Impacts, 19, 59–6419.

Moreno, T., Reche, C., Minguillón, M.C., Capdevila, M., de Miguel, E. & Querol, X. (2017). The effect of ventilation protocols on subway system air quality. Sci. Tot. Environ., 584–585, 1317–1323.

Moreno, T., Reche, C., Rivas, I., (...), Querol, X. & Gibbons, W. (2015). Urban air quality comparison for bus, tram, subway and pedestrian commutes in Barcelona. Environ. Res., 142, 495–510.

Moreno, T. Reche, C., I. Rivas, (...), W. Gibbons, X. Querol. (2015). Air pollution and city travel: choices in commuter exposure to inhalable particulates. J. of Transport & Health, 2, S41-S42.

Reche, R., Moreno, T., Martins, V., (...), Centelles, S. & Querol, X. (2017). Factors controlling particle number concentration and size at metro stations. Atmos. Environ., 156, 169-181.

Triadó-Margarit, X., Veillette, M., Duchaine, C., (...), Casamayor, E. O. & Moreno, T. (2017). Bioaerosols in the Barcelona subway system. Indoor Air., 27, 564-575.

van Drooge, B., Minguillón, M. C. Reche, C., Grimalt, J., Querol, X. & Moreno, T. Air quality in old and new subway systems of Barcelona from analysis of organic tracer compounds. Submitted to journal.

19 Presentations in scientific conferences (in chronological order), Annex XIV

Moreno, T, et al. Implementing Methodologies and Practices to Reduce air pollution Of the subway environment – IMPROVE LIFE. POSTER. 2015 SETAC Europe, 25th Annual Meeting. Barcelona, Spain. May 2015

Moreno, T, et al. Subway particles: what do we breathe on platforms and in trains? ORAL presentation. 2015 SETAC Europe, 25th Annual Meeting. Barcelona, Spain. May 2015

Moreno, T. Air pollution and city travel: choices in commuter exposure to inhalable particulates. ORAL presentation. 1st International Conference on Transport and Health. London, UK. July 2015.

Moreno, T. Key factors influencing air quality in rail subway systems. ORAL presentation. 1st International Conference on Transport and Health. London, UK. July 2015.

Martins, V et al. Particulate matter personal dose in a subway microenvironment. Poster presentation. 2015 European Aerosol Conference (EAC 2015). Milan, Italy, September 2015.

Martins, V. Chemical composition and source apportionment of PM2.5 in subway stations of Barcelona, Spain. ORAL Presentation. 2015 European Aerosol Conference (EAC 2015). Milan, Italy, September 2015.

Moreno, T. What are we breathing in rail subway systems, and why? ORAL presentation. 2015 European Aerosol Conference (EAC 2015). Milan, Italy. September 2015

Moreno, T. Choices in commuter exposure to inhalable particulates. ORAL presentation. 2015 European Aerosol Conference (EAC 2015). Milan, Italy, September 2015.

Moreno, T. IMPROVE LIFE+: Measures to improve air quality in the subway system. Invited Oral presentation. AIRUSE LIFE Final Conference. Barcelona, Spain. April 2016.

Moreno, T. et al. Air pollution exposure while commuting. Invited ORAL presentation. 4th Workplace and Indoor Aerosols Conference. Barcelona, Spain. April 2016

Reche, C. et al. Impact of air pollutants from renewal works in tunnels on subway passenger's exposure. Poster presentation. 4th Workplace and Indoor Aerosols Conference. Barcelona, Spain. 21 April 2016

Martins, V. et al. Exposure to airborne particles in three European subway systems. Presented at the 4th Iberian Meeting on Aerosol Science and Technology (RICTA 2016). ORAL presentation Aveiro, Portugal, July 2016.

Minguillón, MC. et al. Subway aerosol sources and influence of special activities in subway air quality. Presented at the 4th Iberian Meeting on Aerosol Science and Technology (RICTA 2016). ORAL presentation Aveiro, Portugal, July 2016.

Moreno, T. et al. The effect of ventilation protocols on subway air quality. Presented at the 14th International Conference Of Indoor Air Quality And Climate, in Ghent, July 2016.

Minguillón, MC. et al. Aerosol sources and influence of special activities in subway environments. Presented at the 22nd European Aerosol Conference (EAC2016). ORAL presentation Tours, France, September 2016.

Moreno, T. et al. Effects of maintenance works and ventilation settings on the PM concentrations in subway platforms. Presented at the 22nd European Aerosol Conference (EAC2016). Tours, France, September 2016.

Moreno, et al. The oxidative potential of subway PM2.5. POSTER. Congress: 2017 European Aerosol Conference (EAC 2017). Zurich, August 2017.

Moreno, et al. Commuters exposure to airborne microorganisms in the Barcelona subway system. POSTER. Congress: 2017 European Aerosol Conference (EAC 2017). Zurich, August 2017.

Moreno, T. IMPROVE LIFE+: Measures to improve air quality in the subway system. Invited Oral presentation. RESPIRA LIFE Final Conference. Pamplona, Spain. December 2017.

IMPROVE LIFE in the 14th Int. Conference Of Indoor Air Quality And Climate Ghent, Belgium July 3-8.

<u>Other publications</u>

De Miguel, E., Moreno, T. Press release on IMPROVE LIFE in the “Eurotransport magazine” issue for May-June 2015. (Volume 13, 3, pages 62-64; www.eurotransportmagazine.com).


SUSTAINABLE PUBLIC TRANSPORT

Assessing air quality in metro systems

UNPLUGGED inductive charging of electric vehicles

Martins. V. Subway stations with platform sliding doors and good ventilation reduce passengers' exposure to PM2.5. "Science for Environment Policy": European Commission DG Environment News Alert Service, edited by SCU, The University of the West of England, March 2016, Issue 451

Moreno, T. IMPROVE LIFE in The Parliament Magazine – SPECIAL GREEN WEEK EDITION – 16 MAY 2016.


IMPROVE LIFE

Evaluating and improving air quality in subway systems

Articles on IMPROVE LIFE+ in Parliament Magazine.

x) IMPROVE partners have had meetings to inform **stakeholders and policy makers** of the project results. All meetings started with an initial presentation from IMPROVE coordinator T. Moreno, followed by exchange of views among stakeholders to improve the air quality in the subway environment:

30/06/2016: A meeting with Transport for London, attended by IMPROVE coordinator T. Moreno (CSIC) and S. Duffy and S. Quagraine (TfL).

06/06/2017: A meeting with Ayuntamiento de Barcelona (Barcelona City Council). The meeting was attended by T. Moreno (CSIC), E. de Miguel (TMB), and J. M. Craviotto, C. Castells and J. Remirez (Ayuntamiento de Barcelona).

15/09/2017: A meeting with Malaga Metro attended by IMPROVE coordinator Teresa Moreno (CSIC) and J. A. Trujillo Miguel and Rafael Varo Navarro (Metro Málaga).

19/10/2017: A meeting with Metro Bilbao attended by IMPROVE coordinator T. Moreno (CSIC) and A. Galan, I. Apellaniz, JC. Mendoza and JR. Castaño (Metro Bilbao).

23/10/2017: A meeting with Metro Valencia attended by IMPROVE coordinator T. Moreno (CSIC) and M. Gil Guillén (Metro Valencia).

27/10/2017: A meeting with Metro Sevilla attended by IMPROVE coordinator T. Moreno (CSIC) and M. Sánchez (Metro Sevilla).

22/11/2017: A meeting with Renfe, Adif and Madrid metro attended by IMPROVE coordinator T. Moreno (CSIC) and S. Núñez (Renfe), M. Ruiz (Adif), A. Tauler (FFE), F. Fernández (Renfe), C. Rodriguez (Metro Madrid) and A. Robles (Renfe).

28/11/2017: A meeting with the International Association of Public Transport (UITP) attended by IMPROVE coordinator T. Moreno (CSIC) and 13 members of different UITP members (see annex XIX).

06/03/2018: A meeting with Munich Metro was scheduled but finally cancelled by Munich Metro, due to problems with a strike being carried out by subway workers.

07/03/2018: A meeting with Vienna Metro was attended by 12 workers of Wiener Linien, M. Pellot from TMB and T. Moreno from CSIC (see annex XIX).

IMPROVE LIFE meeting with Bilbao (top left) and Malaga (top right), Renfe, Adif and Madrid metro (bottom left) and Barcelona City Council (bottom right)

IMPROVE LIFE in Transport for London (left) and Vienna Metro (Wiener Linien, U-Bahn, right)

IMPROVE LIFE meeting with Valencia metro (left) and the UITP in Rotterdam (middle and right)

xi) A **presentation** was given in the [21st European Forum on Eco-innovation] hold in Sofia, Bulgaria, on 5-6th February 2018, where main results of the project were discussed with all attendants in a series of round tables.

xii) IMPROVE LIFE results have also been shown to TMB workers along the Project during different meetings:

25/01/2016: An update on the IMPROVE results was presented by T. Moreno to the managers of all the different subway lines in TMB (TMB Zona Franca office).

09/03/2016: An update on the IMPROVE results was presented by T. Moreno to the Committee of Work Security (Santa Eulalia TMB office).

11/04/2016: An update on the IMPROVE results was presented by T. Moreno to the TMB Health Committee (Sagrera TMB office).

12/05/2017: An update on the IMPROVE results regarding bioaerosols in the subway system was presented by X. Triadó and T. Moreno to the TMB Safety Committee (Santa Eulalia TMB office).

Table 15. Summary progress of Action D3

		2014	2015				2016				2017				2018
Action		IV	I	II	III	IV	I	II	III	IV	I	II	III	IV	I
D3	Foreseen														
	Actual														

Deliverable		Deadline	Status
5	Minutes of the Open-forum	30/06/2015	Completed
7	Informative leaflets	30/06/2015	Completed
13	6 publications in journals and conferences	31/03/2018	Completed
15	Articles in general and trade press	31/03/2018	Completed
18	Proceedings of the International conference	31/03/2018	Completed
Indicators of implementation			
Leaflets elaborated			Achieved
Articles in local and national press			Achieved
Technical papers submitted and presentations given at international meetings			Achieved
One open forum organised			Achieved
Forum's outcomes published in the project's web site.			Achieved
Organisation of one international conference			Achieved

Continuation after LIFE: More scientific publications and presentations in international conferences based on IMPROVE LIFE results will be produced in the years after the Project is finished. The expenses will be covered by research projects already granted to the CSIC group, including the project led by T. Moreno, lasting from 01/2017-12/2019, and financed by the Spanish Government (CGL2016-79132-R-BUSAIR, 128.000€).

ACTION D4 *Production of Layman's Report*

According to the scheduled timetable this action should have started on July 2016, however, given the large amount of new data obtained during the sampling campaigns, it was subsequently proposed to move forward to January 2017 instead, when the project was more mature and the results fully processed. This suggestion was discussed and agreed with the LIFE Monitoring Team from NEEMO EEIG during their visit in June 2016.

The Layman's Report has been produced containing the most relevant aspects and results obtained within the project in order to increase awareness among policy makers on best measures to improve air quality of subway systems (Deliverable 17). The report includes an introduction, the description of tasks undertaken by the IMPROVE LIFE study to identify the factors controlling air pollution at subway facilities, main results and proposed measures on source reduction and source management to improve air quality at subway systems. The last part of the report includes the most relevant socio-economic benefits of the project, including: policy, effectiveness, air pollution management, employment and public awareness. In order to offer more information about the IMPROVE project it has been included at the end of the document the link to the web page, video and contacts of the coordinator and each partner.

The Layman´s report has been produced in both electronic and paper format. Five hundred copies have been printed, 400 in English and 100 in Spanish. This is a smaller number than originally thought, but it was considered that given the high number of people visiting the project website (1000 visitor/month) the distribution of the report will be highly enhanced if the document was available in the web for downloading. All stakeholders identified during the project are receiving copies and during all dissemination activities that will be carried out from Spring 2018 onwards a copy of the Layman's Report will be included in the documentation distributed.

Table 16. Summary progress of Action D4

		2014	2015				2016				2017				2018
Action		IV	I	II	III	IV	I	II	III	IV	I	II	III	IV	I
D4	Project														
	Solicited														
	Actual														

Deliverable		Deadline	Status
17	Layman´s report	31/03/2018	Completed

5.3 Evaluation of Project Implementation

The project has benefited from a strong team and a lack of staff changes throughout this period, so that continuity of the planned work programme was assured.

The **methodology** applied for all actions has achieved its main objectives. The literature review allowed us to better identify the main pollutant sources in the subway environment, as well as reveal gaps in current knowledge. For the implementation actions we have combined traditional and state-of-the art aerosol measurements with receptor models to investigate the impact of pollution sources in what has been up until now been a poorly understood indoor environment. IMPROVE has motivated subway national and international authorities and stakeholders to adapt and strengthen their current air quality policies. Our protocol to improve air quality in platforms and trains can be condensed into the following series of main points:

- ✓ Recognise the problem and that improvement is possible. Many subway stations have $PM^{2.5}$ levels higher than the legislated limits demanded for outdoor air…. BUT subway stations can be remarkably clean (25 µg/m^3 Collblanc L9S), proving that it is perfectly possible to breathe good air even in the confined space of an underground train network.
- ✓ Commit to an Air Quality Audit for each subway line. The audit will assess existing air quality on platforms and trains.
- ✓ Review the ventilation system. Outdated fan ventilation systems should be replaced by new, more efficient and intelligent designs that minimise the movement of air from tunnels into platforms. Ideally ventilation inlets should be raised above ground to lessen the inflow of traffic-contaminated air, and be capable of responding to exceptional outdoor pollution events. Consider the use of air purifiers on platforms and air conditioning systems inside trains.
- ✓ Reduce fugitive dust emissions underground. Introduce protocols designed to reduce fugitive dust emissions within the underground system, e.g. worker awareness and use of suppressants for ballast laying.
- ✓ Choose non-toxic materials and try to reduce train emissions. Move towards the use of non-toxic materials for moving parts (e.g. Sb in brakes: is it really necessary?), and introducing measures to reduce brake and wheel wear e.g. slowing down the speed of trains in places on lines where there are sharp curves and high gradients.
- ✓ Long term financial planning. Commit to a longer term program designed to maintain improvements achieved. Seek subventions for major works such as the fitting of full length platform screen doors throughout the system.
- ✓ Apply the Air Quality Audit to see where a platform lies on the colour-coded Subway Air Quality Chart introduced by the IMPROVE LIFE project. The application of the proposed PM abatement procedures will aim to move progressively through WHO targets towards the cleanest colour zone (Blue = < 25 µg/m^3).

To summarise the **results achieved** the following table (Table 17) presents tasks foreseen in the revised proposal, tasks achieved and their evaluation.

Table 17. Tasks foreseen in the proposal, tasks achieved so far and their evaluation.

Task	**Foreseen**	**Achieved**	**Evaluation**
Documentation of the current status and selection of critical parameters to be tested	Describe previous studies on air quality in subway systems worldwide. Identify gaps in these studies. Recommend priorities with regards to the emission sources to be tested.	A historical database for air quality in worldwide subway systems was compiled. Parameters poorly studied are particle numbers, size distribution, organic chemistry, microscopy studies, bioreactivity, gaseous components and source apportionment. A prioritisation of pollution sources was produced.	Main parameters to consider in actions B1/B2 were decided as follows: PM, BC and particle number concentrations, inorganic/organic chemical composition, PM size distribution, microscopy (individual particles), toxicity, bioaerosols, NO, NO_2, CO and CO_2 concentrations, and source apportionment. The task was successfully completed.
Determination of the impact of selected parameters	Conduct PM sampling campaigns to check the impact on passenger's exposure to air pollutants attributed to (1) maintenance works in tunnels, (2) use of different brake pads, (3) use of pantographs of different composition (copper vs. graphite), and (4) the deterioration of air conditioner filters in trains.	Sampling campaigns were carried from January 2015 to September 2016. Technical reports were produced every 6 months as indicators of progress. A database detailing the concentrations of chemical tracers for pollutant sources in subway systems was produced. A report on the full impacts on air quality of each of the selected parameters was prepared. A source apportionment study based on the full dataset of chemical analyses was produced.	Results revealed that the activities producing a higher effect on next day platform air quality were rail replacement and welding works. These works could increase $PM_{2.5}$, $N_{0.3\text{-}10}$ and CO levels up to 90%, although the duration of these intense increases tend to be less than 30 minutes. The air quality benefits of operating air conditioning inside train carriages are maintained for at least 3 months without changing the filters. The task was successfully completed.
Testing mitigation measures and development of mitigation strategies	Test on the reduction of resuspensed dust levels in the platforms coming from the tunnel and the variation on air quality in platforms related to changing tunnel fan settings.	Sampling campaigns were carried until November 2016. Technical reports were produced every 6 months as indicators of progress. A nanopolymer material was tested for dust suppression, comparing the standard method (ballast + water) versus the addition of ballast previously treated with the dust suppressant. Different ventilation settings (changing intensity and direction) were tested in Tarragona station (L3). The role of ventilation on air quality was also checked in a new station with platform screen doors (PSD) system (Collblanc).	Results from the first campaign showed that the addition of ballast treated with dust suppressant do not reduce the emission of PM with respect to the standard method during the process. However, the effect of these activities on the following subway operating hours improved when the ballast was previously treated. Nevertheless, this effect was not seen in a second test. $PM_{2.5}$ concentrations are >35% higher when ventilation fans are operating at reduced levels. Reversing subway platform ventilation settings from impulsion to extraction impacts negatively on air quality. Forced mechanical tunnel ventilation is important to maintaining good air quality

			on subway platforms, even in the presence of PSD. All measurements were successfully completed on November 2016, after an adjustment to the timing of the action was agreed with the LIFE Monitoring Team to shift forward deadlines for ending the action in June 2017.
Effectiveness of the project actions	Register the initial situation/evolution of PM. Estimate the reduction that can be achieved with the proposed measures.	The contribution of the selected parameters in the PM levels and compositions is being monitored. An external committee evaluated the progress of the project.	The task was successfully completed.
Assessment of the socio-economic impact of the project	Employment opportunities, knowledge transfer to stakeholders, public awareness, cost-efficiency regulations (to save money and to improve air quality).	General public perception of air quality problems in the subway is annually monitored through questionnaires.	The task was successfully completed.
Project website	Create and continuously updated IMPROVE LIFE website.	The IMPROVE LIFE website was created on December 2014 and contains all information, reports, results, events of the project. It is available in English and Spanish.	The task was successfully completed. All documents, results and reports are available to stakeholders via IMPROVE LIFE website.
LIFE+ Information boards	To design on-site panels describing the project to the general public.	Information boards were designed and installed in all subway sampling sites, and on the premises of the beneficiaries	Information on IMPROVE LIFE project was given to general public.
Organisation of Open forum event	To motivate the dialogue for the reduction in targeted sources at an international level.	Celebration of the Open Forum on air quality in subway systems (07/05/2015) for researchers, stakeholders, public/private organisations and the public in general.	Stakeholders from the local City Council, Auton. Gov. of Catalonia, Barcelona Public Health Agency and Ferrocarrils de la Generalitat attended the event. The task was successfully completed.
Informative leaflet	Produce a leaflet to present IMPROVE LIFE.	An informative leaflet was designed, produced and disseminated.	This task was successfully completed.
Articles in the press, media	To communicate IMPROVE LIFE through the media and the press	63 media and press articles were released (including digital and paper press, radio and TV interviews)	High visibility was given to IMPROVE LIFE project. This task has been successfully implemented.
Technical publications	Submission of 6 technical papers in international journals and presentation in international conferences.	16 technical papers have been published in international journals, and 19 presentations of IMPROVE LIFE results have been given in international conferences.	This task has followed the foreseen timetable and has over-exceeded its initially planned targets.
Organisation of events	Organize events to disseminate IMPROVE LIFE results.	Celebration of an Expert's Workshop Special Session on "Commuter air quality in rail	The task was successfully implemented.

		subway systems" (06/05/2015) within the SETAC Europe 25th Annual Meeting.	
Organisation of International Conference	An international conference to present IMPROVE LIFE results.	An international conference was held in Barcelona on 2017 (date July 3-4th RICTA).	The task was successfully completed.
Networking with other projects.	Establish cooperation with institutions, authorities and European stakeholders that have been involved on air quality mitigation measures.	IMPROVE LIFE has started collaborations with other LIFE projects and visit stakeholders including Transport for London, Vienna Metro, Barcelona City Council, Malaga, Bilbao, Valencia, Sevilla and Madrid Metros, Renfe, Adif and the International Association of Public Transport (UITP).	The task was successfully completed. UITP meeting was attended by specialists of more than 15 international public transport operators, covering a wider group of companies in just one travel to Rotterdam.
Elaborate project summary reviews	Every 3 months, where the progress of all activities and deliverables is reported.	14 summary reviews of the project progress have been elaborated.	The task was successfully completed.
Layman´s report	Prepare and disseminate the Layman´s report.	Prepared and delivered on time	The task was successfully completed.
After-LIFE+ Plan	Prepare/disseminate the After-LIFE+ communication Plan.	Prepared and delivered on time	The task was successfully completed.

The dissemination actions of the project have so far generated an encouraging level of public interest when publicised through the project website, 63 media and press releases (including digital and paper press, radio and TV interviews), 16 publications in scientific journals, 19 presentations in conferences, the organization of 1 workshop and 1 international conference held in Barcelona on 2015 and 2017 respectively. Furthermore 6 technical reports were produced and 1 technical guide, all available in IMPROVE website http://improve-life.eu/documents/reports-list/.

Therefore, the dissemination activities carried out during the project have shown a great success, involving general media, local questionnaires for subway commuters and meetings with 11 stakeholders that have shown their interest in the air pollution mitigation measurements indicated in the technical guide (**distributed to all subway systems worldwide**, Annex XIII), showing IMPROVE results to all public intended. All objectives proposed within the project have been achieved, and the results of this are already visible.

5.4 Analysis of long-term benefits

Environmental benefits

Given the current lack of a legislative framework for indoor air quality, despite the importance of indoor air pollutants with regard to actual daily exposure of urban inhabitants, the results from the IMPROVE project are well placed to guide more effective National and Local regional development policies regarding the atmospheric environment (in accordance also with the requirements of Directive 2008/50/EC for air quality plans formulation). More specifically, the environmental benefits from IMPROVE include quantifying the impact of pollution sources in the subway system, recommending specific measures for the improvement of air quality, supplying the decision-making transport authorities in European member states with a valuable tool for subway planning, encouraging the exchange of experience and practical knowledge between scientist and transport authorities, and directly promoting a decrease in adverse health outcomes (premature mortality and hospital admissions, among others) and thus improve the life quality of European urban citizens.

Long-term benefits and sustainability

The long term benefits predicted to arise from IMPROVE LIFE, and the increased general awareness of the importance of air quality that this project encourages, will include:

- Further incentivise the use of low emission public transport and implementation of protocols aimed at providing cleaner commuter air as an effective tool for the abatement of atmospheric urban pollution.
- Health problems alleviated by subway air quality improvement will result in fewer hospital admissions. The consequent cost benefits will include fewer respiratory and/or cardiovascular problems leading to savings in medicine, physician, medical tests, hospitalization, and loss of wages due to illness.
- Energy savings related to implementing the most appropriate ventilation settings for each subway line and more efficient protocols for a/c filter replacement.
- Changes in commuting habits, as promoting cleaner subway air will encourage a larger number of passengers to choose the subway systems instead of private transport.
- Motivate the transport authorities and stakeholders to adopt new and constructive PM mitigation measures, through meetings with stakeholders and other subway systems.
- New business and employment opportunities in the area of air pollution mitigation will be generated by, for example, research and development of new products suitable for the application of tunnel and platform dust suppressants and more efficient and “air quality friendly” ventilation systems.

Replicability, demonstration, transferability, cooperation

Since the beginning of the project significant replication efforts have been made, as the aim of the project is to present pollution mitigation measurements applicable to all subway systems worldwide. Thus a strict protocol was established for all measurements, with monitoring campaigns being carried out a minimum of twice, and at different times of the year, and with monitoring equipment being located in the same location at all times, to minimise the influence of other parameters in the analysis.

Using IMPROVE methodology and dissemination, any subway operator worldwide now has full access to clear guidelines as to how to characterise the spatial and temporal variability of particulate matter, and determine the sources and their impact on the air quality of the station platform.

Various meetings with stakeholders to present and discuss IMPROVE LIFE results have been carried out, including: Metro Bilbao, Metro Valencia, Metro Sevilla, Metro Madrid, Renfe (Spanish National Railway Network), Barcelona City Hall, Adif (owner of Spanish rail infrastructure), Transport for London, Vienna Subway (U-Bahn), and the International Association of Public Transport (UITP, Rotterdam). In all meetings the IMPROVE technical guide for improving air quality in the subways systems was presented as a keynote reference publication to which all future mitigation actions should be referred, especially with respect to the innovative colour-coded diagram for subway air quality improvement presented in the guide.

The cooperation of all TMB technical personal was key for the development of the project. In relation to this, annual meetings with TMB workers to discuss IMPROVE LIFE progress, especially in relation to subway worker's exposure (TMB Safety Committee) were held in TMB main offices since the beginning of the project.

Best practice lessons

In the framework of the project, we have identified the main subway pollutant sources and prioritised cost-effective air pollution mitigation strategies. One of the core tasks was to work directly with Public Transport authorities, improving their awareness of air quality and encouraging their development of best practice policies designed to improve underground atmospheric conditions. The outcome will be communicated and promoted by a proactive outreach dissemination programme directly involving relevant transport authorities in European cities.

The excellent existing links between scientific researchers in CSIC and the engineers and managers of the TMB system, who have a proven reputation for their high commitment to making environmental improvements to their transport system and are always enthusiastically co-operative, provides a unique opportunity for collaboration which, to our knowledge, has no equal worldwide. This collaboration has offered significant "added value" to the project outcomes and will encourage the adoption of new "air quality friendly" subway protocols, not only in Barcelona but in other underground transport systems worldwide. The following Table summarises the abatement measures involved in the project proposals for better subway air, and offers a qualitative approach to the relative costs and benefits involved.

Cost/benefit analysis of the IMPROVE LIFE proposed abatement measures to improve subway air concentrations.

<table>
<tr><th colspan="3">ABATEMENT MEASURES</th><th>BENEFIT</th><th>COST</th></tr>
<tr><td rowspan="2">SOURCE REDUCTION</td><td colspan="2">Indoor source: Selected train components, avoiding known toxic compounds. Specific recommendations:
-Brakes with the lowest % in Sb and Cu.
-Graphite pantographs.
-Brushless motors.</td><td>- Lower passenger exposure to air pollution, associated with a reduced emission of toxic heavy metals.</td><td rowspan="2">- Differential cost of alternative materials and supplies.</td></tr>
<tr><td colspan="2">Outdoor source: Selected location of new metro stations' ventilation grills, avoiding high traffic areas.</td><td>- Lower passenger exposure to air pollution, associated with a reduced entrance of outdoor pollutants.</td></tr>
<tr><td rowspan="5">SOURCE MANAGEMENT</td><td rowspan="2">Ventilation settings</td><td>Forced ventilation at tunnels and platforms.
Specific recommendations:
-Impulsion of outdoor air at platforms during metro hours.
-Strong ventilation at platforms (> 25 Hz).
-Ventilation at tunnels always connected during metro operating hours.</td><td rowspan="2">- Lower passenger exposure to air pollution, associated with reduced PM concentrations.</td><td rowspan="2">- Installation.
- Maintenance.
- Energy costs for equipment operation.</td></tr>
<tr><td>Air conditioning systems inside trains.</td></tr>
<tr><td colspan="2">Air purifiers in platforms and trains</td><td>- Lower passenger exposure to air pollution, associated with reduced PM concentrations (dependent on the distance to the passenger and flow rate).</td><td>- Acquisition.
- Installation.
- Maintenance.
- Energy costs for equipment operation.</td></tr>
<tr><td colspan="2">Maintenance works. Specific recommendations:
- Timing of nocturnal maintenance works. They should be conducted as early in the night as possible.
- Use of dust suppressant when laying ballast.</td><td>- Increased passenger exposure to coarse particles averted.
- Lowering early daytime platform $PM_{2.5}$ concentrations by at least 10%.</td><td>- Cost of dust suppressant product (unless only water is used).</td></tr>
<tr><td colspan="2">Platform Screen Doors (PSD)</td><td>- Reduced exposure to tunnel-generated pollutants.
- Passenger security.</td><td>- Maintenance.
- Energy costs for doors operation.</td></tr>
</table>

Innovation and demonstration value

The IMPROVE project has used a complementary collection of different methodologies aiming to elucidate differences in air quality between the old and new lines, under differing ventilation conditions in platforms and tunnels, different platform designs, different catenaries, with trains using different brake pad compositions, different air filters in trains, and after different tunnel maintenance activities. A series of techniques have been applied, these including complete chemical analysis of inorganic and organic (polycyclic aromatic hydrocarbons) compounds in $PM_{2.5}$ quartz microfiber filters and morphological and size analysis of individual particles by means of Electron Microscopy. The combined database, including both levels and chemical composition, has allowed application of statistical analysis to identify main emissions sources of PM (mechanical abrasion of rail/wheel, brakes and catenaries, resuspension of material caused by air turbulence in the stations and tunnels, night-time maintenance works, and ambient road traffic particles), whereas the microscopy study of these particles has given us information not only on the size but also the shape of the particles, which is also related to the originating source.

Measurements have been also systematically measured at different points in each platform in order to evaluate the representativeness of the PM measurements carried out in the sampling sites (these being normally located at one end of the platform for safety and logistic reasons). Real time measurements have been also obtained from within trains of the metro lines where stations have been measured, under different types of air conditioning filters. All these measurements have been carried out at least twice, and at different times of the year, in order to compare changes in variables such as air conditioning ventilation. Complementary measurements of ambient street aerosols have been obtained by utilizing on-going monitoring in an urban background site in Barcelona.

An innovative aspect was the use of these complementary techniques to identify best cost-effective measures aimed at achieving optimal air quality in subway systems. The experience gained by the project is being disseminated through Transport Authorities and other key stakeholders worldwide

Long term indicators of the project success

Future results of a successful IMPROVE LIFE project will be based on long term indicators such as the following:

- Adoption by Transport Authorities of mitigation measures developed in the framework of the project (such as better ventilation settings, use of dust suppressants when adding ballast, changes in the use of specific subway components regarding brakes and catenaries).
- Update of air pollutant concentrations, chemical components and their sources in the subway environment to encourage the assessment of new measures designed to improve subway air quality.
- Decrease of PM concentration levels on subway platforms and inside trains as a result of the adoption of air quality improvement measures recommended by IMPROVE LIFE.
- Improvement in the health of subway passengers and workers.
- Development of legislation on air quality in the subway/indoor environment.

5.5 List of Deliverables

- Deliverable 1: Project website (Action D1), presented with IncR (English/Spanish)
- Deliverable 2: A historical PM level and chemical composition database (Action A1), presented with IncR
- Deliverable 3: Information boards (Action D2), presented with IncR (English/Spanish/Catalan)
- Deliverable 4: Review on air pollutant sources and suggestion of parameters to test (Action A1), presented with IncR
- Deliverable 5: Minutes of the Open-forum (Action D3), presented with IncR
- Deliverable 6: Minutes of the expert´s workshop (Action E3), presented with IncR, updated
- Deliverable 7: Informative leaflets (Action D3), presented with IncR (English/Spanish/Catalan)
- Deliverable 8: Report on main air pollutant sources contribution (Action B1), presented with MtR, updated
- Deliverable 9: Report of mitigation measures in subway systems (Action B2)
- Deliverable 10: Technical guide for mitigation measures (Action B2)
- Deliverable 11: Questionnaires for the public and stakeholders (Action C2), (English/Spanish/Catalan)
- Deliverable 12: Report on policy effectiveness of the project (Action C1)
- Deliverable 13: Publications in journals and conferences (Action D3), updated
- Deliverable 14: After-Life Communication Plan (Action E4) (English/Spanish)
- Deliverable 15: Articles in general and trade press (Action D3), updated
- Deliverable 16: External audit and financial reports (Action E1)
- Deliverable 17: Layman´s report (Action D4) (English/Spanish)
- Deliverable 18: Proceedings of the International conference (Action D3)
- Deliverable 19: Projects reports (Action E1)
    - IncR: Inception Report
    - MtR: Midterm Report
- Deliverable 20: Report on socio-economic impact (Action C2)
- Deliverable 21: Summary reviews on project progress (Action E2), updated

Implementing Methodologies and Practices to Reduce air pollution Of the subway enVironmEnt LIFE13 ENV/ES/263

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