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An environmental, economical and socio-political analysis of a variety of urban air-pollution reduction policies for primary PM10 and NO_x: The case study of the Province of Milan (Northern Italy)

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ABSTRACT

In the frame of urban air-pollution reduction policies, economic costs and environmental benefits of a variety of actions have been quantitatively assessed for the Province of Milan (Northern Italy), focusing on PM10 and NO_x emission sources.

Short-to-mid-term interventions that have been taken into consideration include reduction of inner temperature in residential buildings, banning of residential biomass heating systems, banning of diesel fuelled domestic boilers, night-time streets washing, speed limit reduction on highways, circulation restrictions of oldest EURO vehicles, conversion of diesel buses to natural gas, car sharing/biking promotion, DPF adoption in diesel vehicles, extension of road lanes for urban buses, energy efficiency refurbishment in residential buildings.

Re*sults emerged from the cost–benefit analysis integrated with socio-political indicators obtained through direct surveys, will contribute, with an holistic and multidisciplinary approach, to drive the local administrators to implement the most suitable actions in one of the most polluted areas in west-Europe.

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1. Introduction

Atmospheric pollution in highly anthropized and populated areas is widely recognized as a serious problem that may lead to severe health effects to population (WHO, 2013). Particulate matter (PM) and NO_x are among the atmospheric pollutants of major harm in many urban areas.

Milan, which is the main city in Northern Italy, is subject to very critical atmospheric pollution conditions for both PM and NO_x. In Milan the annually averaged concentration of PM10 (the regulated fraction of PM, comprehensive of particles with an aerodynamic diameter less than 10 μm) and NO_x in the last four years (2009–2012) were 45 $\mu g\,m^{-3}$ and more than 50 $\mu g\,m^{-3}$ respectively (ARPA Lombardia, 2012), above the

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yearly EU limit value for the protection of human health of 40 $\mu g\,m^{-3}$ for both PM10 and NO_2 (2008/50/EC).

It is important to underline that, according to the same European Directive (2008/50/EC) for NO_x a yearly critical value of 30 $\mu g\,m^{-3}$ is foreseen for the protection of vegetation and ecosystems. While critical levels are fixed on the basis of scientifical knowledge about possible effects only on vegetation and ecosystems, limit values are stated in order to prevent harmful effects on both human health and ecosystems. Bad air quality in Milan is enhanced by adverse meteorological conditions, mainly in winter, with low dispersion factor that favors accumulation processes of pollutants at sites in the Northern Italy basin (Ferrero et al., 2011).

The contribution to concentrations of pollutants in Milan comes from several primary emission sources. Source apportionment studies have estimated the contribution of primary emissions sources influencing the air quality levels in Milan, by distinguishing the relative contribution of primary emissions which are local (set in the urban area) or not (coming from the widespread regional sources). If the wider Milan metropolitan area (including the city and its urbanized surroundings) is taken into consideration, the PM emitted locally results the major contribution (over 50%) of the annual mean primary PM10 concentrations in Milan (Bedogni and Pirovano, 2011). The estimated contribution of local emissions to annual mean NO_x concentration in Milan is even higher (80–90%) (ENEA, 2012). This means that, despite of the different regional sources contribution, the local PM and NO_x primary emission sources within the Milan metropolitan area are an important burden to air quality in Milan. Thus undoubtedly the definition of effective policies to reduce primary emissions of PM10 and NO_x over the Milan metropolitan area are a challenging task.

In this study we focus on the Milan metropolitan area corresponding to the administrative boundaries of the Province of Milan, represented by 134 Municipalities.

From the Regional Emissions database, the Inventory of Emission in AiR (INEMAR, 2010), it emerges that in the Province of Milan residential combustion and transport on road are the macro-sectors that show the most relevant contributions in terms of annual emissions of both primary PM10 and NO_x. According to the most recent INEMAR database for the year 2010 (INEMAR, 2010), the residential sector covers about 24% of primary PM10 emissions in the Province of Milan, while the transport on road sector (direct emissions) about 58%. Even considering NO_x emissions, the annual contributions of the residential and transport on road sectors with respect to total emissions in the Province of Milan amount to about 12% and 71% respectively. The other emission sources (with particular reference to industrial processes, agricultural practices, wastes management, ...) are less or not relevant.

In this work we performed calculations for the primary PM10 and NO_x emissions in the Province of Milan from the two macro-sectors, traffic and residential heating, by considering the reference year 2010 and projecting the emissions to 2015. While the Regional INEMAR database only estimates the direct traffic source, in this study we considered for traffic both the direct and indirect (resuspension of road dust) PM10 emissions (Section 2.2.1). Various studies report that among several European cities a large part (50% and more depending on the location) of the total traffic PM10 emissions can originate from the indirect traffic source (Amato et al., 2010; Bukowiecki et al., 2010; Ketzel et al., 2007).

The most innovative aspect of this study concerns the analysis, by a multidisciplinary approach, of a wide portfolio of both emergency and structural (to be deployed in the short-to-medium term, respectively) actions aimed to reduce primary emissions of PM10 and NO_x due to both traffic and residential heating sectors in the Province of Milan. We evaluated the environmental effectiveness associated to several actions which could be undertaken in the area of the Province of Milan, estimated as the annual emissions abatement (expressed in tons year^{-1}; t y^{-1}). Along with the environmental outcome, for each measure we estimated the direct economic costs (expressed in million euro year^{-1}; M€ y^{-1}) supported by both public authorities and private citizens to identify a "priority list" in terms of environmental effectiveness and economic efficiency. Moreover, environmental and economic data have been integrated with social and political data concerning the effectiveness perceived and the real policy implementation degree for each action considered.

To our knowledge no other studies exist that combine environmental, economic, social and political evaluations to analyse so many atmospheric policies, in both transport on road and residential sectors, that could be applied to the Milan metropolitan critical area. Also this work shows a holistic, multidisciplinary approach that can be exported to other urban areas worldwide for the assessment of different pollution abatement strategies.

2. Materials and methods

2.1. *Description of emission reduction actions*

Up to 15 reduction actions in the transport (10) and residential heating (5) sectors have been analysed in terms of environmental benefits and direct economic costs associated to their application in the Milan metropolitan area.

With regard to the transports sector, the proposed actions have been grouped under four different areas, namely: sustainable public transports, private mobility, DPF installation on diesel vehicles and PM10 resuspension. In Table 1 we report the list of the specific actions that have been envisaged and their belonging sector/area.

Each action is classified as emergency (EA), short term, or structural (SA), medium term, action.

For each action we have considered a certain implementation level (scenario). Each scenario corresponds to a certain degree of action implementation, and the estimation of both environmental impacts and costs of an action necessarily depends on the specific scenario considered, as also reported in Table 1. For each action the most "realistic" scenario was defined by taking into account previous studies and data, when existing, for the specific area of Milan and/or other literature studies. The Province of Milan, which commissioned the study, collaborated in recovering local information and data for Milan, which were also useful in hypothesizing the scenarios of action implementation. For some actions (four actions: A2, A4, A7 and A10) a unique scenario has been

Table 1 – Emissions reduction of primary PM10 and NO_x (t y^{-1}) due to the application of each single action and related costs (M€/y). For the year 2010: emergency actions (EA) only; for the projection to year 2015: emergency actions (EA) + structural actions (SA).

Estimated total (residential + traffic sector) emissions in the province of Milan (t y^{-1})					2010			2015		
Sector	Area				PM10_10	NO_x_10		PM10_15	NO_x_15	
				Residential + traffic	3144	20676		3083	16705	
				residential[a]	657	3761		910	4892	
				traffic[b]	2487	16915		2173	11813	
		Actions			EA only			EA and SA		
		No.	Policy description	Scenario	PM10_10 (t y^{-1})	NO_x_10 (t y^{-1})	Cost_10 (M€ y^{-1})	PM10_15 (t y^{-1})	NO_x_15 (t y^{-1})	Cost_15 (M€ y^{-1})
Residential sector		A1	Reduction of inner T in residential buildings (EA)	LOW (21 ?C)	22.9	171.1	−96.0	22.1	228.4	−152.0
				HIGH (19 ?C)	68.3	510.7	−286.4	66.0	681.8	−453.6
		A2	Banning of domestic stoves and fireplaces (EA)	Heating provided by NG	316.7	38.4	−1.0	–[c]	–[c]	–[c]
		A3	Enhanced energy efficiency in residential buildings (SA)	LOW (G to F, F to E)	SA	SA	SA	2.0	410.0	75.8
				HIGH (G to F, F to E, E to D, D to C)				3.0	575.0	106.2
		A4	Banning of diesel-fuelled domestic boilers (SA)	Diesel boilers are substituted by NG boilers	SA	SA	SA	53.7	67.1	−28.8
Traffic sector	Sustainable public transports	A5	Free/subsidized public transports use during ferial days (period: 15/10–15/04) (EA)	LOW (−5% private vehicles; +50% LPT)	20.6	−1.5	0.02	18.3	6.0	0.1
				HIGH (−20% private vehicles; +50% LPT)	113.0	419.6	3.73	90.5	232.9	4.3
		A6	Conversion of public buses to natural gas (SA)	LOW (Conversion of Euro 2, 3 buses without DPF)	SA	SA	SA	3.5	−30.3	−2.3
				HIGH (Conversion of all Euro 1, 2, 3, buses)				3.7	−71.0	−0.8
		A7	Dedicated lanes for public buses circulation (SA)	urb (V_{ave} = 40 km/h); extraurb (V_{ave} =60 km/h)	SA	SA	SA	5.5	193.0	12.0
		A8	Development of the new underground lines (SA)	LOW Development of M4 line	SA	SA	SA	8.5	32.0	56.5
				HIGH Development of M5 line	SA	SA	SA	64.2	234.0	127.3
	Private mobility	A9	Circulation restriction to diesel vehicles without DPF during ferial days (period: 15/10–15/04) (EA)	LOW Euro 0,1 and 2 diesel vehicles without DPF (3 days-winter period)	1.9	19.4	−7.5	0.8	8.1	−3.3
				HIGH Euro 0, 1, 2, 3 and 4 diesel vehicles without DPF (3 days-winter period)	5.9	44.3	−24.5	2.6	18.1	−11.6
		A10	Speed limit reduction on extraurban roads (EA)	Max speed: 70 km/h	41.0	340.8	−28.6	3.4	182.2	−56.9
		A11	Circulation banning during weekend days for private autovehicles (period: 15/10–15/04) (EA)	LOW Stop to circulation for 3 weekend	15.8	72.1	−60.7	12.4	38.8	−61.8
				HIGH Stop to circulation every 2 weekend	69.3	316.0	−266.0	54.2	170.2	−271.0
		A12	Bike use fostering (SA)	LOW Bike use share: 6%	SA	SA	SA	39.8	119.7	−289.3
				HIGH Bike use share: 20%				132.7	399.0	−761.6
		A13	Car sharing (SA)	LOW Domain covered: 60%	SA	SA	SA	9.5	35.8	23.9
				HIGH Domain covered: 80%				12.6	47.3	30.1
	DPF instal	A14	DPF installation on diesel commercial vehicles (Euro 0–4) (SA)	LOW DPF application LDV	SA	SA	SA	161.8	0	10.9
				HIGH DPF application LDV + HDV				275.6	0	13.9
	PM10 resusp	A15	Enhanced streets washing during night time (period: 15/10–15/04) (EA)	LOW 20% urban streets	8.3	0	0.5	7.8	0	0.5
				HIGH 50% urban streets	20.8	0	1.2	19.5	0	1.3

[a] Residential emissions were derived by INEMAR for 2010 and estimated for 2015.

[b] Traffic Emissions (direct + indirect) were calculated as described in Section 2.2.1 and Supplemental Material 2.

[c] Action A2 is an already implemented policy (see even the assumptions reported in Supp Mat 1, action A2). Thus, it has been restricted to the year 2010 and not considered for the year 2015.

assumed, that is when the realistic alternative seemed to be undertaking that action or not (e.g. A10: the speed limit reduction is imposed on all extraurban roads of the Province of Milan, or the action is not taken even). For most actions (11 actions: A1, A3, A5, A6, A8, A9, A11, A12, A13, A14, A15) we reported two different scenarios corresponding to a minimum (LOW scenario) and to a maximum (HIGH scenario) implementation level that could be envisaged. Detailed information on actions and scenarios considered are reported in Supplemental Material 1.

2.2. *Estimates of environmental emissions*

2.2.1. *The traffic sector*

PM10 primary emissions from traffic may come from direct or indirect source. The direct source is the sum of two contributions: exhaust emissions of vehicles, and tyre, brake and road wears caused by vehicles' motion. The indirect source of primary PM10 emissions from traffic is due to resuspension of loose material on the road surface. Primary direct PM10 and NO_x emissions and primary indirect PM10 emissions associated with on road transport have been estimated for the Province of Milan. The methodology that was followed together with the calculation performed and input data used are described in detail in Supplemental Material 2.

Briefly, primary direct PM10 and NO_x emissions from traffic were estimated by following the methodology of the European Environmental Agency (EEA, 2013), calculating the annual emissions of pollutants (primary direct PM10 and NO_x) ($t\,y^{-1}$) from the vehicles fleet circulating in the Province of Milan (ACI, 2013).

Primary PM10 emissions from indirect source, related to the contribution of resuspension from the vehicles fleet circulating in the Province of Milan, have been evaluated by the methodology proposed by EPA (EPA, 2011). The emission factor we calculated for PM10 from road resuspension in the Province of Milan (39 $mg\,km^{-1}\,vehicle^{-1}$) is in agreement with the values that were estimated in other European urban areas too (Table S13). The estimated annual PM10 emission (year 2010) in the Province of Milan was 1063.6 $t\,y^{-1}$ from the indirect traffic source, and the total (direct + indirect) traffic PM10 emissions were 2487 $t\,y^{-1}$. Thus the indirect traffic PM10 emissions are a significant contribution (43% in 2010) to total traffic PM10 emissions in the Province of Milan, as also reported by Bukowiecki et al. (2010) for Zurich (56%). Moreover, because of the decreasing trend of exhaust direct PM10 emissions, the relative contribution from indirect emissions to total traffic related PM10 source is estimated to be even higher in 2015 in the Province of Milan (Tables S14 and S15).

In the traffic sector, eleven different actions have been envisaged. The specific data and elaborations for primary (direct + indirect) PM10 and NO_x emissions reduction calculation for each considered action are outlined in Supplemental Material 1.

2.2.2. *The residential heating sector*

Primary PM10 and NO_x emissions associated with residential heating for the Province of Milan have been derived by the Regional INEMAR database (INEMAR, 2010).

In the residential heating sector, five different policies have been envisaged and specific methodologies for primary PM10 and NO_x emissions reduction calculation have been applied.

The methodologies and data (INEMAR, 2010; ARPA Lombardia, 2010; Caserini et al., 2011) that have taken to the estimates of primary PM10 and NO_x emission reductions from actions in this sector are outlined in Supplemental Material 1.

2.3. *Estimation of direct economic costs*

Due to the wide set of actions analysed and different contexts of implementation, only direct costs were evaluated, while indirect costs, like social and environmental costs, were not taken into account (Amann et al., 2011; Chae, 2010).

Economic data (Eurostat website: http://epp.eurostat.ec.europa.eu/portal; Eubionet III IEE Project website: www.eubionet.net; Chamber of Commerce of Vicenza website: www.vi.camcomm.it) refer to the price of energy inputs (i.e. natural gas, LPG, biomasses), use costs (i.e. average cost per km), implementation costs for single actions (i.e. car sharing, bike use fostering, substitution of traditional buses with natural gas fuelled ones), service delivery costs (i.e. public transports) and investment costs (i.e. DPF, dedicated lines for buses). Data related to actions concerning public transports directly come from the balance sheets of the local public transport companies of the Municipality and Province of Milan. Due to the variety of costs typologies, their collection has been a big effort in the study.

All input costs (energy prices, operating costs of vehicles, public transport costs) have been projected up to 2015 according to the average of Eurostat transport and energy price indexes of the last ten years. In particular energy prices assume constant excise taxes and an evolution in line with energy inflation (thus excluding exogenous shock in the energy market).

The variety of actions to be evaluated posed a big challenge in terms of evaluation method. For that reason a case-by-case bottom-up approach has been adopted (DEFRA, 2005), using local level data (where available) or literature data where a specific evaluation has not been possible (EPA, 2006). Each measure has been evaluated independently. Due to the emergency nature of many actions no change in habits, thus costs, have been factored in. However, these changes have been taken into account in actions A8, A12 and A13 (Laurino and Grimaldi, 2012), due to their structural nature.

Considering the classification reported by Sternhufvud et al. (2006), we considered the abatement costs both for consumers and producers and the implementation costs for the policy maker (Table S16). The abatement cost could be positive or negative: for example the circulation banning (action A11) entails a saving, that is a negative cost, for the non-use of the private car, but a positive cost due to the use of public transport as a substitute mean of transport, resulting in a net negative cost (Table 1).

Emergency actions have taken into account only changes in use of vehicles or in the energy mix and not investments (such as car substitution, or installation of new heaters, or building renovation).

In structural actions, where both operating and capital costs (investment costs) occur, the equivalent annuity cost (a financial tool to evaluate the cost per year and operating an asset over its entire lifespan) has been calculated in order to get the annual cost to compare it with the results due to emergency actions.

2.4. *Questionnaires to the local administrators to assess the effectiveness perceived and real policies implementation degree*

Once defined the list of policies in Table 1, the effectiveness perceived by all the 134 Municipalities belonging to the Province of Milan and their real application level have been investigated in order to finally match the survey results with environmental and economic data coming out from the cost–benefit analysis.

Actually, a questionnaire has been distributed to all the Majors of the 134 Municipalities belonging to the Province of Milan whose answers would have demonstrated the effectiveness perceived in terms of environmental benefits and the real implementation potential associated to each policy considered in this study. Since the Majors answered to the questions after consulting NGOs and focus groups representative of citizens interests (i.e. Association of Entrepreneurs, Chamber of Commerce, Freight Companies, Public Transport Companies) we can consider the answers to the questionnaires (in terms of effectiveness perceived and real implementation degree of single policies) as socio-political indicators representative of the interests of people living in the single Municipalities.

The questions have then been grouped under the first 4 different policy areas that are described in detail in the following (Section 3.2). Actually, policies whose implementation is subjected to private and not public decisions (DPF installation on LDVs and HDVs, Action A14) have been excluded from the questionnaire.

With reference to the single policies, a score between 0 and 5 has been attributed both to the effectiveness perceived and real policy implementation degree by 95 Municipalities over 134 (the feedbacks representativeness from questionnaires have been around 71% and reported in Supplemental Material 4). We attributed the value ''MINIMUM'' to scores between 0 and 3, ''MEDIUM'' to score 4 and ''MAXIMUM'' to score 5.

Aim of the questionnaire has been the verification of the real implementation of policies at a Province level (and not just at one single Municipality level) since only a common implementation could lead to a significant emissions reduction of primary PM10 and NO_x in the studied area.

3. Results and discussion

3.1. *Emissions reduction of primary PM10 and NO_x and costs related to each single policy (year 2010 and 2015)*

The emissions reduction of primary PM10 and NO_x associated to the application of single policies (each one declined into specific scenarios), along with their related costs (positive or negative) that affect public administrators and/or privates depending on the different actions considered are represented in Table 1.

Actually, up to 15 actions (A1, ..., A15) have been considered and most of them foresee different scenarios of policies implementation (LOW and HIGH scenarios) that take to different PM10 and NO_x emissions abatement potential.

Results are presented for the reference year 2010, for which only EAs are considered, and for the projection to year 2015, when both EAs and SAs are supposed to be implemented. Action A2, which is an EA, has only been considered for 2010 since it is an already implemented policy (banning of domestic stoves and fireplaces) that will not be applied again in the mid-term.

As it is shown in Table 1, EAs undertaken in year 2015 always take to less environmental benefit (lower emissions reduction of primary PM10 and NO_x) than that is estimated for the year 2010. This is due to the combination effect of two aspects: the implementation of the envisaged SAs in 2015 reduce the net effect of the EAs in both the residential and the traffic sector; the evolution of the vehicle fleet throughout the years, with more vehicles of the new EURO classes which are characterized by lower pollutant emissions (Perrone et al., 2014), reduce the environmental benefits obtained by EAs in the traffic sector.

3.2. *Emissions reduction of primary PM10 and NO_x and costs related to the five action areas (year 2015)*

In the following we present all the environmental policies that have been analysed (Table 1), grouped in five different areas of interest, that is:

- **Residential Sector** with regulations concerning domestic heating (Actions A1–A4);
- Increase of **Sustainable Public Transports** (Actions A5–A8);
- Limitations/regulations for **Private Mobility** (Actions A9–A13);
- DPF Installation on diesel vehicles (Action A14);
- Reduction of **PM10 Resuspension** from street surfaces (Action A15).

The minimum and maximum emissions abatement potentials and costs are estimated for each area for the projection to year 2015: the minimum emissions abatement potential is calculated by considering that all individual policies (EAs and SAs) of each action are adopted according to the LOW scenario, while for the maximum emissions abatement potential all individual policies are supposed to be adopted in the HIGH scenario (see Table 1).

3.2.1. *Emissions abatement potential for the different action areas*

The minimum and maximum abatement potential of primary PM10 and NO_x emissions in the Province of Milan are pictured respectively in Fig. 1a (PM10) and Fig. 1b (NO_x) for the five action areas. The emissions abatement is reported as min–max $t\,y^{-1}$ and as relative percentage (%) decrease to total emissions abatement potential (with respect to the sum of the contributions of all action areas) in the Province of Milan. All five action areas determine an emission reduction of primary PM10, while only three (Residential Sector, Limitations/Regulations for Private Mobility and Sustainable Public Transports) affect the abatement of NO_x emissions.

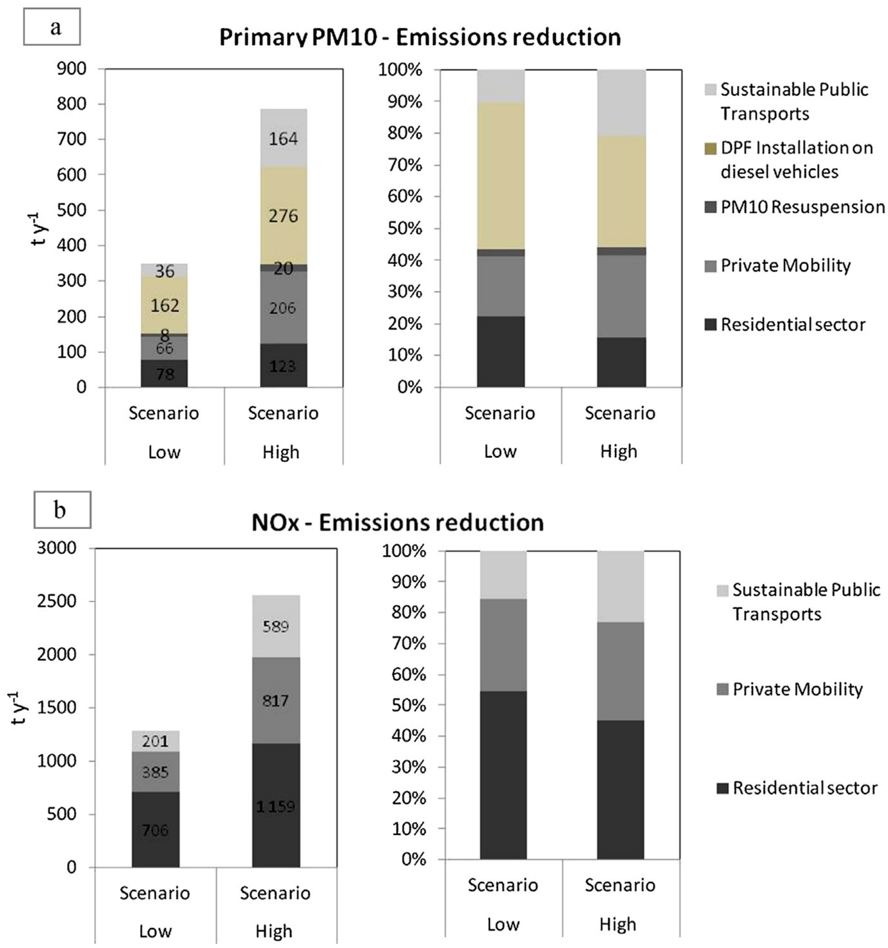

Fig. 1 – Minimum (Low Scenario) and Maximum (High Scenario) emissions abatement potential (expressed in t y^{-1} and %; year 2015) of primary PM10 (a) and NO_x (b) due to the adoption of all policies belonging to each area of interest.

PM10 total abatement potential as the sum of the contributions of all action areas is estimated to range between a minimum of 349 t y^{-1} to a maximum of 787 t y^{-1}, the HIGH scenario taking to a PM10 total abatement more than double the LOW scenario. Policies associated to the Residential Sector area are estimated to produce a reduction of 78 up to 123 t y^{-1} for PM10 emissions, corresponding to 16–22% as relative contribution to PM10 total abatement potential. With reference to the reduction of PM10 Resuspension by streets washing, PM10 emission abatement is limited, with an estimated contribution of 8–20 t y^{-1} (2% of PM10 total abatement potential). A low amount of abated emissions of PM10 from street cleaning was estimated also for other European cities, like Barcelona (<1% of PM10 daily traffic emissions) (Amato et al., 2009; Chang et al., 2005; Norman and Johansson, 2006).

Considering limitations and regulations for Private Mobility, primary PM10 emissions could be reduced from a minimum of 66 t y^{-1} to a maximum of 206 t y^{-1} corresponding to 19–26% as relative contribution to PM10 total emissions abatement potential. Actions falling under the Sustainable Public Transports area take to a reduction of 36–164 t y^{-1} of primary PM10 emissions, contributing 10–21% to the total. Lastly, the DPF installation on diesel vehicles (HDVs and LDVs) determines an abatement of 162–276 t y^{-1} of PM10 annual emissions in the Province of Milan. DPF installation on diesel vehicles is a single policy and it takes to the maximum PM10 abatement potential which we have estimated for each of the 15 single policies (Table 1), its relative contribution to the sum of the contributions of all action areas ranging between 46% (LOW scenario) to 35% (HIGH scenario) (Fig. 1a).

NO_x total emissions abatement is estimated to range between a minimum of 1291 t y^{-1} to a maximum of 2565 t y^{-1}: as for PM10 emissions abatement, the considered HIGH Scenario takes to a NO_x total emissions abatement which is about double the LOW scenario (Fig. 1b). The Residential Sector area, with domestic heating measures, is able to take to the highest reduction of NO_x emissions in the range 706–1159 t y^{-1} (45–55% of the NO_x total abatement potential for HIGH and LOW scenarios, respectively). Actions associated to Private Mobility and Sustainable Public Transport areas contribute respectively to 385–817 t y^{-1} and 201–589 t y^{-1} of NO_x emission reduction, corresponding to 30–32% (Private Mobility) and 16–23% (Sustainable Public Transports) of NO_x total emissions abatement in the Province of Milan (Fig. 1b).

Thus, considering the implementation of all policies in the traffic sector (HIGH scenarios), annual emissions reduction of primary PM10 and NO_x up to 31% and 12% respectively with respect to the overall 2015 emissions from traffic estimated for the Province of Milan could be achieved. Considering the implementations of policies in the residential sector (HIGH scenarios), it will take to a 13% emissions reduction of primary PM10 and a 27% NO_x emissions reduction with respect to the overall emissions estimated for this specific sector for the Province of Milan for the year 2015 (INEMAR, 2010; ENEA, 2011).

3.2.2. *Costs for action areas*

With reference to the same areas of interest specified above it is possible to summarize the results of the costs analysis, according to the same LOW and HIGH scenarios (Table S17).

Total net economic benefits from the sum of actions reach 345 and 1553 M€ y^{-1} in the LOW and HIGH Scenario, respectively. These amounts roughly correspond to 12–32% reduction of the total heating and private car usage costs incurred in the Province of Milan.

It is worth repeating that each measure has been assessed independently from each other. In policy areas A1, A2 and A5 this method does not represent a problem. Possible shortcomings could arise, however, in policy areas A3 and A4 where several measures may overlap (e.g. A5 and A9, A9 and A13, A11 and A12, A9 and A12, A9 and A13). This can both amplify or limit the overall effectiveness of the actions if implemented together.

3.2.3. *Cost–benefit analysis*

The integration of environmental and economic data is here presented, through a cost–benefit analysis to compare environmental benefits and costs of different policy measures. For each of the five action areas, the costs (M€ y^{-1}) of specific policy measures depending on the yearly primary PM10 (Fig. 2) and NO_x (Fig. 3) avoided emissions (t y^{-1}) are reported. In this cost–benefit analysis results of both LOW (see Supplemental material 5) and HIGH (Figs. 2 and 3) scenarios are reported, that is: benefits and costs are estimated by supposing that all individual policies are adopted according to LOW and HIGH scenarios (Table 1).

The contributions of histograms are cumulated to obtain the total PM10 and NO_x emissions abatement potential due to the application of all actions according to LOW or HIGH scenarios,.

Each histogram represents a single policy, and different policies of the same action area are ordered in the graphs from left to right by increasing costs. It can be noticed that action A2 is missing since, as specified in Section 3.1, its implementation is not considered for the year 2015.

Fig. 2 shows that all policies take to primary PM10 emissions abatement while costs can be positive or negative (savings) depending on each single action considered: high PM10 emission abatements corresponding to big economic savings are mainly related to the Residential (e.g. A1) and Private Mobility (e.g. A12) areas. Positive costs are related to actions belonging to Resuspension (A15), Sustainable Transports (A5, A7 and A8) and DPF installation (A14).

Fig. 3 shows that the implementation of all policies leads to NO_x emissions abatement (the highest emissions reduction is attributed to actions belonging to the Residential area) with one exception given by A6 that shows an increase of NO_x emissions. Costs reported are the same of Fig. 2.

3.3. *Effectiveness perceived and real implementation of policies*

In order to compare the questionnaire results with the cost–benefit analysis we grouped the single policies under

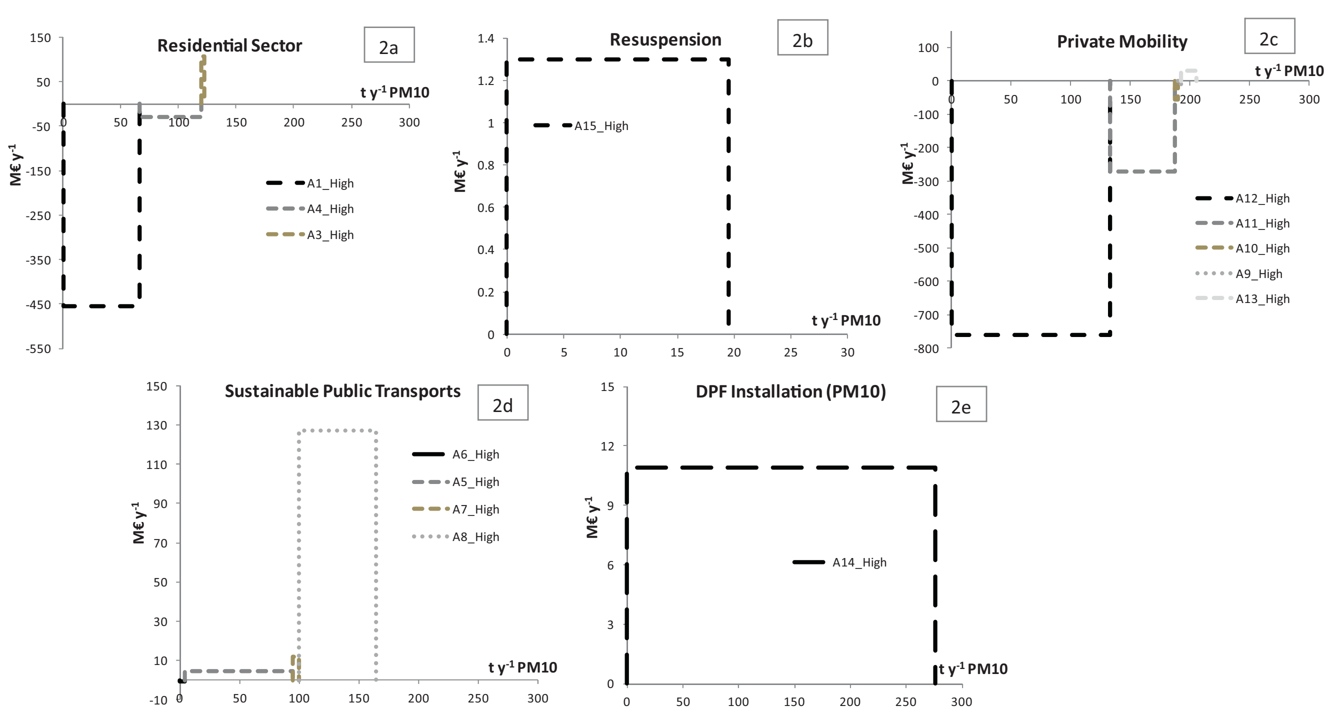

Fig. 2 – Primary PM10 avoided emissions (positive values, in t y^{-1}) versus costs (positive/negative, in M€ y^{-1}) for each single action (High Scenario, year 2015) divided in the 5 areas investigated (a, b, c, d, e). Actions are represented in the graph according to increasing costs.

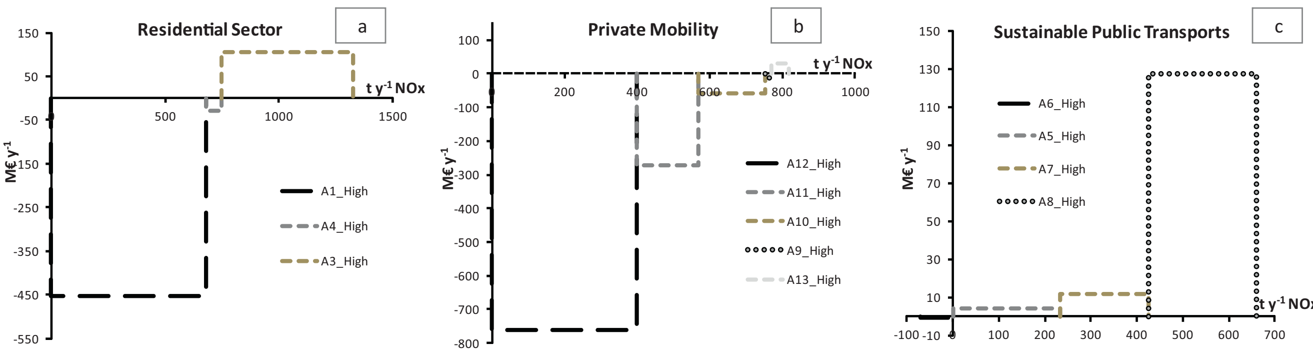

Fig. 3 – NO_x avoided emissions (positive values, in t y^{-1}, increasing emissions are represented as negative values) versus costs (positive/negative, in M€ y^{-1}) for each single action (High Scenario, year 2015) divided in the 3 areas investigated (a, b, c). Actions are represented in the graph according to increasing costs.

the same policy areas (residential sector, private mobility, sustainable public transports and PM10 resuspension) and estimated an average effectiveness perceived and implementation degree in percentage with respect to the overall feedbacks (about 71% of the total number of Municipalities belonging to the Province of Milan, see Supplemental material 4), with respect to the different assigned values (MINIMUM, MEDIUM and MAXIMUM) associated to policies belonging to the different investigated areas (Table 2). We underline once again that the area concerning DPF installation on diesel vehicles has been excluded since it only includes policies taken over at a private and not public level.

In general, the effectiveness perceived and the implementation degree for the actions have matching values: most frequently, to a MAXIMUM effectiveness perceived corresponds a MAXIMUM implementation degree as well to a MINIMUM effectiveness perceived corresponds a MINIMUM implementation degree. These correspondence occurs for all the actions, except A15 (street washing activities), for which the effectiveness perceived is MEDIUM, but the implementation degree is MINIMUM, and A8 (development of new underground lines), for which a MEDIUM value of effectiveness perceived is reported, but the implementation degree results MAXIMUM (Fig. 4).

As can be seen from Table 2, the highest percentages (values evidenced in bold characters) of effectiveness perceived and implementation degree for the policies related to the traffic sector-Sustainable Public Transports area and Residential Sector area, are always MEDIUM or MAXIMUM. On the contrary, actions A9, A10, A11 belonging to Traffic

Table 2 – Effectiveness perceived and implementation degree for all policies investigated (*only exception: A14). Values are reported in percentage (%) with respect to the overall feedbacks (95 of 134 Municipalities belonging to the Province of Milan answered the questionnaires). In bold characters the highest percentages for the actions.

ACTIONS (A1–A15*)	Effectiveness perceived			Implementation degree			Sector – *area*
	MIN %	MED %	MAX %	MIN %	MED %	MAX %	
Reduction of Internal temperatures in residential buildings (A1)	25.3	**47.4**	27.4	18,9	**54.7**	26.3	**Residential sector**
More restrictive regulations and controls for public buildings (A2–A4)	10.0	**46.8**	43.2	8.9	**52.1**	38.9	
Incentives for the enhancement of energy efficiency in private buildings (A3)	1.4	36.1	**62.5**	3.5	45.3	**51.2**	
Incentives and fostering of public transports (A5–A8)	36.5	**38.7**	24.9	36.1	**42.9**	21.1	**Traffic sector – Sustainable public transports**
Enhancement of environmental performance of public transports (A6)	0.0	35.8	**64.2**	0.0	35.8	**64.2**	
Development of devoted lanes for public transports (A7)	16.8	32.6	**50.5**	25.3	42.1	**32.6**	
Stop to private vehicles circulation (A9–A11)	**54.3**	32.0	13.7	**53.5**	31.2	15.4	**Traffic sector – Private mobility**
Restrictions to vehicles speed (A10)	**49.5**	42.1	8.4	**43.2**	40,0	16.8	
Bike use fostering (A12)	10.5	43.2	**46.3**	4.2	46,3	**49.5**	
Car sharing (A13)	13.0	**57.5**	29.5	16.5	**51.2**	32.3	
Enhanced street washing activities during night time (A15)	41.1	**43.2**	15.8	**70.5**	21.1	8.4	**Traffic sector – PM10 resuspension**

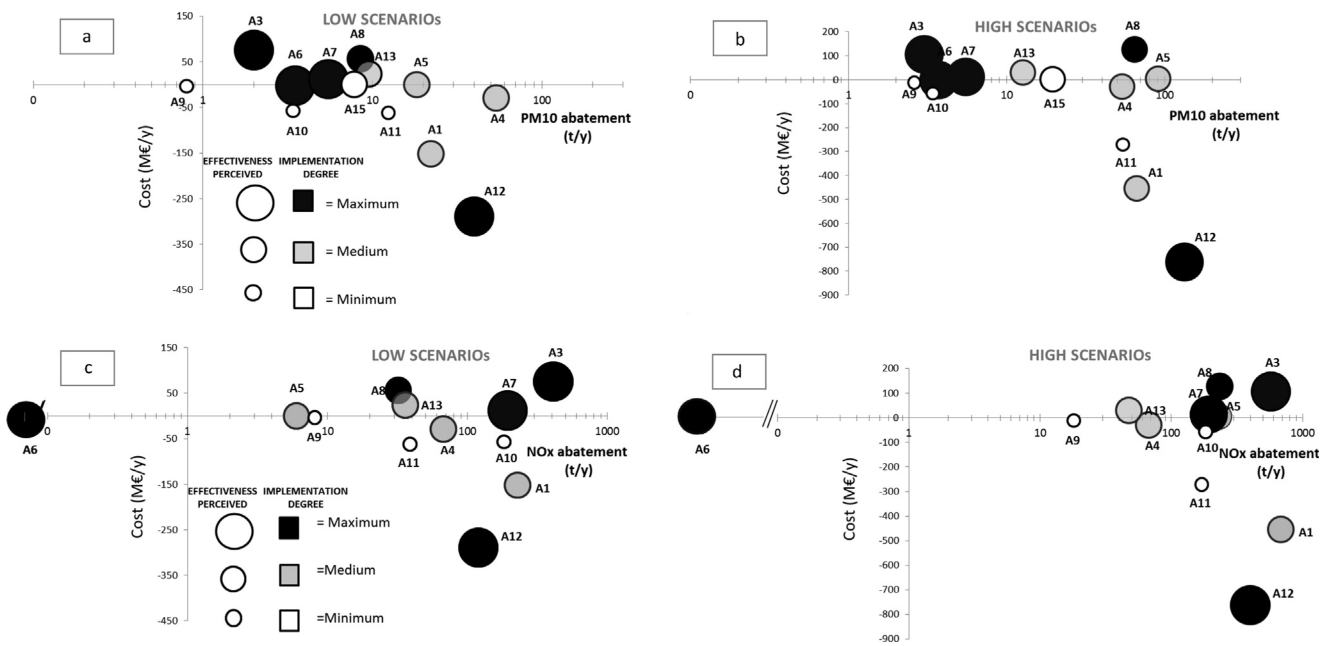

Fig. 4 – Primary PM10 emissions abatement (t y^{-1}, a and b), and NO_x emissions abatement (t y^{-1}, c and d) estimated for each action (year 2015) in relation to the estimated cost (M€ y^{-1}) (y axis), actions effectiveness perceived (point size) and real implementation degree (point colour). Note that both PM10 and NO_x emissions abatement values on the x axis are reported in a log scale (for enhanced graphical representation of the results).

sector–Private Mobility area, do not encounter a positive social and political acceptance (they all show MINIMUM socio-political indicators) despite they are all cost-saving and show emission reductions, in particular in relation to NO_x (Table 1).

3.4. *Environmental, economic and social/political data integration (year 2015)*

In this paragraph, 13 out of the 15 total actions are reported, for which all data (environmental, economic and socio-political) are available. A2 is not included as we consider the year 2015, while it was restricted to the year 2010; A14 is not reported as social data are missing. As it was explained in Section 3.3, A14 is related to a policy taken at private level, and no feedbacks have then been foreseen from the public administrators about the effectiveness perceived and the implementation degree.

Fig. 4 summarizes the results of the integration of environmental benefits, economic costs and socio-political data for the 13 reported actions.

Results for each action are pictured, by reporting on the x axis the estimated PM10 emissions abatement (t y^{-1}) (Fig. 4a and b: respectively the LOW and HIGH scenario) or NO_x abatement emissions (t y^{-1}) (Fig. 4c and d: respectively the LOW and HIGH scenario), and on the y axis the estimated costs (M€ y^{-1}), referred to the year 2015. The size and colour of each point (action) in the graph represent, for each action, the effectiveness perceived and the implementation degree, respectively. The effectiveness perceived and the implementation degree are both categorized under a three-value scale (MINIMUM, MEDIUM or MAXIMUM as explained in Section 3.3).

Interesting results have emerged combining environmental, economic and social data for all the considered actions.

First of all, it emerged that there are some actions which present a MAXIMUM value of effectiveness perceived and implementation degree though the associated pollution abatement estimate is not high. It is for example the case of A6 (conversion of diesel public buses to NG use) for which the effectiveness perceived as well as the implementation degree is MAXIMUM, but the primary PM10 emissions abatement estimated for the Province of Milan is not very promising (from 3.5 to 3.7 t y^{-1}) (Fig. 4a and b) and, even more relevant, for this specific action an increase, rather than an abatement for NO_x emissions have been calculated (see Fig. 4c and d, that present negative NO_x emissions abatement from −71 to −31 t y^{-1}). Similarly, also A7 (Dedicated lanes for public buses circulation) and A3 (Enhanced energy efficiency in residential buildings) presents MAXIMUM values for both the effectiveness perceived and the implementation degree despite the estimated environmental results which were not necessarily promising for both PM10 and NO_x. In particular, for A7 and A3 the estimated reduction of polluting emissions was limited for PM10 (5.5 t y^{-1} and 2.5 t y^{-1}, respectively), while the estimated abatement was more promising for NO_x, in particular for A3 (A7 = 193 t y^{-1}; A3 = 492.5 t y^{-1}, the highest NO_x abatement in Fig. 4c). Some additive impacts can be considered, which could also be further examined in detail by other specific studies. Actually, new devoted lines for public transport vehicles circulation (A7) could lead to a reduction of traffic congestion in urban areas as well as increase the public transport services demand in substitution of private vehicles use, thus enhancing the potential environmental impact already foreseen by the action implementation.

On the contrary, it also occurred that some actions scored a MEDIUM or at least a MINIMUM value of effectiveness perceived and implementation degree despite a significant estimated emissions abatement. For example, for A1 (Reduction of inner temperature in residential buildings) a PM10 emissions abatement of 22–66 (LOW-HIGH) t y^{-1}, and a higher emissions abatement of 228–682 t y^{-1} for NO_x (the second highest value in Fig. 4b), in the Province of Milan has been calculated, but the values of effectiveness perceived and implementation degree are ''only'' MEDIUM. Also A11 (Circulation banning during ferial days for private vehicles) could take to promising results of average emissions reduction of both PM10 and NO_x (LOW-HIGH: 12–54 t y^{-1} and 39–170 t y^{-1}, respectively), though presenting a MINIMUM score of both effectiveness perceived and implementation degree. If we consider the estimation of costs related to A1 and A11, we notice that both actions take to a net cost saving (negative values on the y axis of Fig. 4), so these actions would be surely environmentally and economically viable.

Thus, despite it was estimated that some actions would take to benefits for the environment (high pollutants emissions abatement) and for the economical costs (a net cost saving), not always the same actions encountered a MAXIMUM score of effectiveness perceived and implementation degree.

By combining environmental, economic and socio-political data, it appears that one of the actions which is most promising (showing both environmental and economic benefits) and, at the same time, operatively viable (showing MAXIMUM values for both the effectiveness perceived and the implementation degree), is A12 (bike use fostering). Actually, A12 is the most cost-effective action for the estimated PM10 abatement (see Fig. 4b and c). A1 is the closest action to A12 considering its cost-effectiveness, but its effective achievement would be limited by the lowest effectiveness perceived and implementation degree (MEDIUM instead of MAXIMUM).

Starting from the responses to the questionnaires by local administrators, we can consider only actions that registered the highest score (MAXIMUM) for implementation degree, as such actions (namely A3, A6, A7 and A12) are the ones that most probably will be adopted in the Province of Milan in agreement with what expressed by the various Municipalities as their intention to act. In this case, the total emissions abatement are in the range 59–209 t y^{-1} and 724–1330 t y^{-1} for primary PM10 and NO_x respectively, where the minimum and maximum emissions abatement values refer to LOW and HIGH scenarios considered in Table 1. On the contrary, if we consider the actions that have been evaluated with a MINIMUM implementation degree by local policymakers (Actions A9, A10 and A11 and A15: the ones that most probably will not be adopted in the Province of Milan), the total emissions abatement are in the range 24–80 t y^{-1} and 229–370 t y^{-1} for primary PM10 and NO_x respectively, where the lowest and highest emissions abatement values refer to LOW and HIGH scenarios considered in Table 1. The comparison between PM10 and NO_x emissions abatement depending on the policy implementation degree (MAXIMUM/MINIMUM implementation level in most cases reflect a MEDIUM-to-MAXIMUM/MINIMUM effectiveness perceived level too) shows that the set of actions that are going to be implemented at the Province level in the short-to-mid-term will lead to greater PM10 and NO_x emissions abatement potential with respect to the ones that are not considered strategic for the local administrators. Even the total costs related to the implementation of actions that have been evaluated with a MAXIMUM implementation degree by local administrators are lower (up to 35% economic savings) than the ones associated to a MINIMUM implementation degree.

4. Conclusions

From this study a priority list of environmental policies to be adopted at urban level has emerged, evaluating each policy considering the integration of environmental, economic and socio-political aspects.

With reference to the environmental benefits, the implementation of all policies leads to an annual emission reduction of primary PM10 and NO_x, except for action A6 (Conversion of public buses to natural gas fuel) which could result in an increase in NO_x emissions. The total emissions abatement for all 15 policies considered is up to about (HIGH scenarios) 787 t y^{-1} for primary PM10 and 2565 t y^{-1} for NO_x, that is 26% (PM10) and 15% (NO_x) reduction of the overall 2015 emissions estimated for the Province of Milan from traffic on road and residential sectors.

It is important to underline that all results about PM10 emissions abatement potential due to the implementation of all actions considered only refer to primary PM10 so that all results are not related to the PM10 secondary fraction that also contributes to PM10 atmospheric concentrations (Perrone et al., 2012).

With reference to the direct costs associated to each single policy, it is interesting to note that most of the policies are related to negative costs mostly due to savings in fuel consumption (both for transports and residential sectors). Direct positive costs are mostly associated to the investments necessary for the development of new underground lines and dedicated lanes for public buses, car sharing promotion, the creation of a subsidy systems to foster public transports use, DPF installation on LDV and HDV diesel vehicles (the latter are only private born costs in absence of public subsidies) and by enhanced street washing activities during night time.

Nevertheless, low implementation costs, even if in presence of potentially high net savings, had not often led in the past to concrete coordinated actions. One possible explanation may be a problem of public acceptance for actions that actually affect personal habits or diverging goals and needs between municipalities.

A MEDIUM to MAXIMUM effectiveness perception of most of the policies has been verified at local level and it was discussed for common implementations over the 134 Municipalities belonging to the Province of Milan, even supported by the encouraging results of the cost–benefit analysis. In this sense, action A12 (bike use fostering) was the one that best matches cost–benefit results and socio-political acceptance.

Furthermore, summing up primary PM10 and NO_x emissions abatement potential due to the implementation of all actions (HIGH scenario) associated to a MAXIMUM implementation level, values up to 6.8% and 8.3% can be evaluated for primary PM10 and NO_x respectively with respect to the total emissions for the Province of Milan due to emissions projections related to traffic on road and the residential sector estimated for 2015.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.envsci.2014.07.012.

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