Evolution of Air Quality in Paris between 2002 and 2012

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This study quantifies the responsibilities of various parameters related to road traffic in the evolution of air quality in Paris between 2002 and 2012.

In this study, air quality is characterized by concentrations of nitrogen dioxide (NO_2) and particles (PM10, PM2.5). In Paris, these pollutants are mainly emitted by road traffic. In addition, these three pollutants exceed recursively regulatory values (limit values) in the Paris region and especially in the heart of the city both in background situation and close to traffic roads. France is currently in dispute with Europe for non-complying with the Directive "Clean Air for Europe" regarding PM10 standards. For nitrogen dioxide, the procedure has just been initiated.

Emissions of carbon dioxide (CO2) from road traffic were also evaluated, the City of Paris has a goal of 25% reduction of greenhouse gas emissions (GHG) by 2020 compared to 2004.

The first part of the study presents the evolution of air quality between 2002 and 2012 while the second part estimates the impact of different parameters on this evolution: evolution of traffic (number and speed of circulating vehicles), composition of vehicle fleet and technological park, share of NOx in the atmosphere as NO_2 (ratio NO_2/NOx), background concentrations.

10-years evolution of air quality in Paris

Evolution of traffic in 10 years: the traffic data were provided by the City of Paris for nearly 900 km of roads modelled (Paris and "Périphérique" – i.e. ring road). These data shows that traffic on the ring road decreased by 6% between 2002 and 2012 and by 15% in Paris. This modelled trend is consistent with the traffic counts performed over the same period, which show a decrease of 6% of traffic on the ring road and 21% on main roads in central Paris. There is an overall decrease in traffic with deviated traffic on secondary roads. The average speed shows a decrease, whether in Paris and on the ring road.

Evolution of the fleet in 10 years: the fleet characterizes the distribution of traffic flow into the following categories of vehicles: Passenger Cars (PCs), Light Duty Vehicles (LDVs), Heavy Duty vehicles (HDVs), Buses and Cars (BCs) and Two Wheelers (2Ws). Since 2002, the fleet has changed significantly, as evidenced by regular surveys conducted by the Department of Roads and Transportation of the City of Paris. The share (in vehicles.kilometers) of PCs in Paris and on ring road decreased from 80% to 70% in 10 years. On the contrary, there was an increase in the share of motorized two-wheelers in the fleet. On morning and evening rush hours, more than one vehicle over 5 traveling in Paris today is a motorized two-wheeled vehicle.

Evolution of the technological park in 10 years: the technological park defines "Euro" standards and motorizations (type of fuel) for each vehicle category. Euros standards establish emission limits for vehicles regarding different pollutants and over a standard driving cycle. In ten years, the technological park has evolved significantly with the introduction of vehicles with NOx and particulates emissions subject to more stringent Euro standards, including the arrival of Euro 4 and Euro 5 standards for PCs.

For the year 2002, the technological park was evaluated based on the Global Transportation Survey 2001 (EGT) and for year 2012, it was determined based on a survey conducted in 2010 by the City of Paris. In 2002, nearly half (44%) of kilometers traveled by PCs in Paris were due to pre-Euro and Euro 1 vehicles. Ten years later, they represent only 8% (see Figure 1).

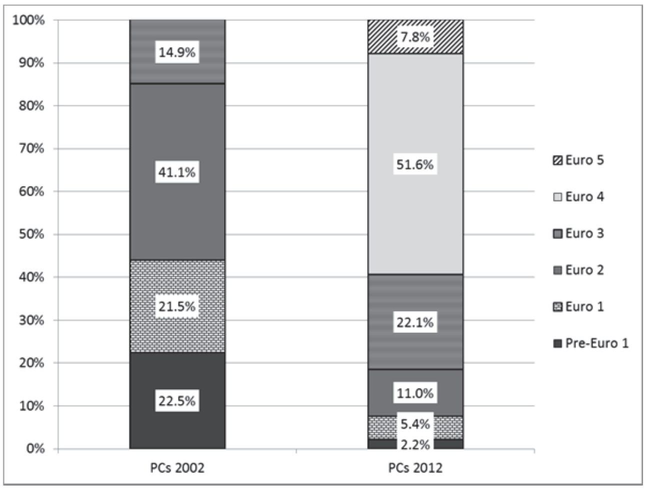

Figure 1: Share of mileage run by personal cars (PCs) as a function of Euros standards in Paris in 2002 and 2012.

Euro 2 individual vehicles accounted for the majority of PCs (more than 40% of traffic) in 2002, while in 2012 they accounted for only 11%. Euro 4 and 5 standards that did not exist in 2002 now cover more than half of kilometers travelled by PCs in Paris in 2012.

This technological change is accompanied by a change in motorization: in 2002, the large majority of PC was powered by gasoline compared to diesel, the trend was reversed in 2012 with over 60% of vehicles.kilometers travelled in Paris by diesel powered PC.

<u>Evolution of pollutant emissions related to road traffic in 10 year:</u> based on these input parameters, the calculation of road traffic emissions was achieved. These emissions data were calculated with the HEAVEN system, a traffic related emission calculation chain Airparif developed within the European project HEAVEN and has regularly been updated during the past decade. The European database of emission factors COPERT IV (EMEP / EEA, 2012) is used for the calculation. This allows computing hourly emissions of Parisian traffic for each axis of the modeled road network.

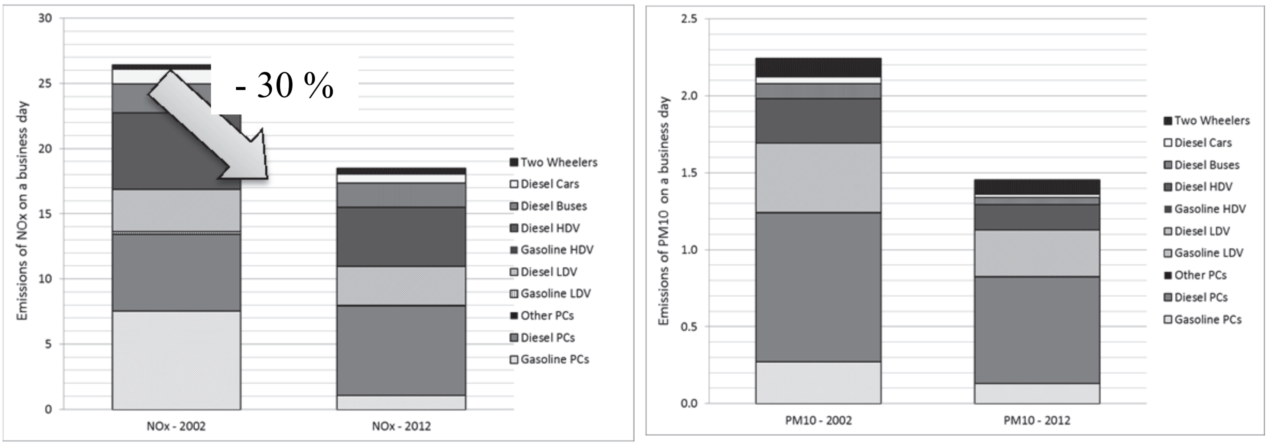

Figure 2: Emissions of NOx and PM10 on a working day due to Parisian traffic in 2002 and 2012, by categories of vehicles.

Figure 2 shows the evolution of NOx and PM10 emissions between 2002 and 2012 for an average working day, distinguishing the contribution of the different vehicle categories.

For all pollutants, emissions from road traffic between 2002 and 2012 decreased by 30% (NOx) and 40% (PM2.5), due to decreasing traffic flows and the evolution of the technological park toward a cleaner park.

The decrease of carbon dioxide emissions is lower (-13%). Indeed, in COPERT IV methodology as regards PCs, fuel consumption and therefore CO_2 emissions are considered stable from the Euro standard 4; on the contrary, the most recent regulations (Act No. 2009-967 relative to the implementation of the “Grenelle de l’Environment”, EC 443/2009 and No. 510/2011 regulations) require reductions in emissions, and have already been implemented (EEA, 2013).

The most significant change concerns diesel vehicles. Despite both the modernization of diesel vehicles (Euro 4 and 5 standards) and the overall decline in traffic volume, the increase in NOx emissions related to diesel PCs (17%) is generated by the significant increase in diesel PCs circulating in Paris. Regarding PM10 particles, the amount of emissions from diesel PCs fell by 29%. However, the contribution of diesel PCs to particles emissions related to road traffic increased from 43% of PM10 in 2002 to 48% in 2012. Differences in trends in NOx and particles emissions are due to emissions limitations more stringent for particles than for nitrogen oxide.

Dieselization of the PCs park generates a very significant reduction in emissions compare to gasoline powered PCs. Thus, the two factors combined, namely the evolution of the technological park in favor of less pollutant vehicles and lower kilometers traveled by gasoline powered PCs in favor of diesel powered PCs. NOx emissions for this category of vehicles decreased by 86% and over 50% for particulate matter and carbon dioxide. The contribution of gasoline PCs to the total NOx and CO_2 emissions also decreased significantly from 29% of emissions to only 6% for the NOx and 44% to 22% for the CO_2. For particles, the contribution of gasoline PCs also declined but in a more reduced way (from 12% to 9%).

Based on Airparif emission inventories (July 2013), atmospheric emissions in Ile-de-France declined between 2000 and 2010 about 40% for nitrogen oxides (38%), PM10 (36%) and PM2.5 (42%). Sectors related to the production & consumption of energy and waste treatment distribution have seen their emissions of NOx and particulates reduced by more than 50% over this period, the highest emission reduction. This significant decrease is primarily the result of new regulations related to the Atmospheric Protection Plan (PPA in French) adopted in 2005 for incinerators and Large Combustion Plants (LCPs).

<u>Evolution of air quality in 10 years:</u>

Annual mean concentrations of NO_2 and particulate matter (PM2.5 and PM10) were mapped on the basis of:

i) background levels, calculated using the CHIMERE model (IPSL / CNRS-INERIS) and kriging of observations measured at stations from Airparif network;
ii) emissions from road traffic to assess concentrations close to traffic roads with the software STREET;
iii) empirical relationships to describe gradually decreasing pollution levels away from major roads.

This mapping process of air quality in background situation and proximity to road traffic is shown in Figure 3.

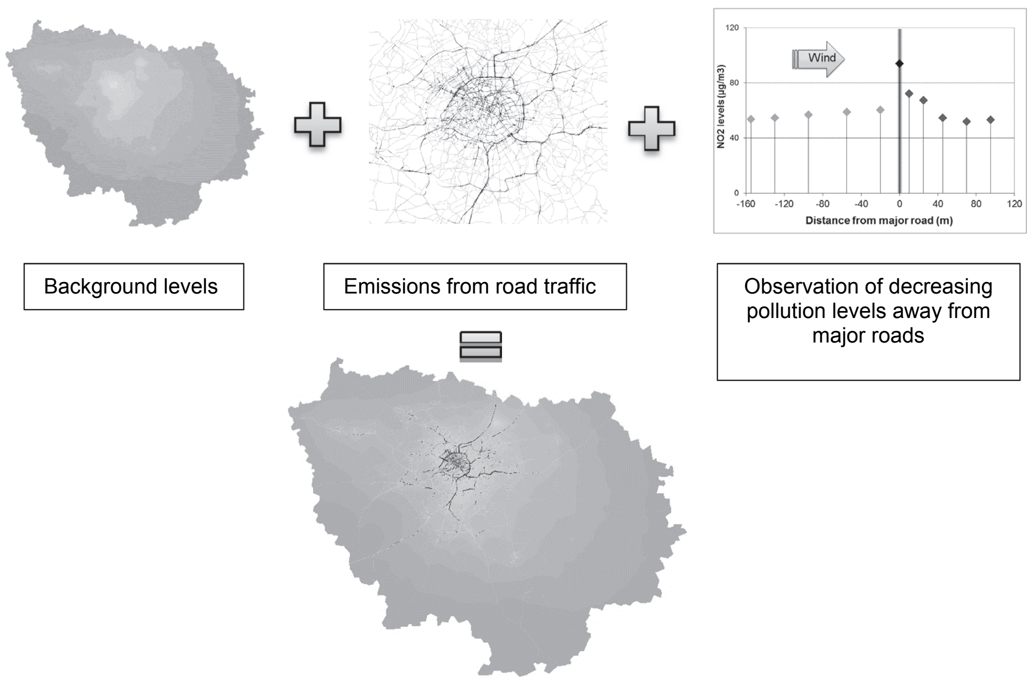

Figure 3: General principle of the modeling approach and mapping of pollutant levels.

To allow the direct comparison of average annual levels of PM10 and PM2.5 in 2002 and 2012, 2002 levels were revalued to take account of regulatory metrological developments (taking place in January 2007). A comparison was made between measurements performed simultaneously with the old and the new methods on two stations of Airparif permanent network (Paris-Gennevilliers and Paris-18th district) for a history of six years (2007-2012). Measurement equipment taking into account the semi-volatile particles recorded at the two sites measured an increase of 35% of annual levels. Background levels throughout the Ile-de-France have thus been adjusted (factor 1.35 applied to investigate the evolution of particle concentrations over the 2002 / 2012 period.

Concerning nitrogen dioxide, annual concentrations are derived by applying a ratio NO_2/NOx to NOx modeled levels. This ratio is calculated based on concentrations measured on traffic stations in Ile-de-France, after subtracting background levels to be as close as possible to the ratio NO_2/NOx. Between 2002 and 2012, this ratio evolves significantly, due to the widespread use of catalyzed particulate filters. Thus, the primary NO_2 emissions increased in ten years from 15% to 22% of NOx emissions (Airparif March 2013).

Evolution of pollutant concentrations: maps established for 2002 and 2012 are compared to quantify the evolution of the air quality over the period. It is directly possible because regarding the weather, years 2002 and 2012 are not atypical years as the years 2003 (heat wave - lack of rain) and 2001 (precipitation well above the average level). The maps (see Figure 4 and Figure 5) show a significant decrease in annual levels between 2002 and 2012.

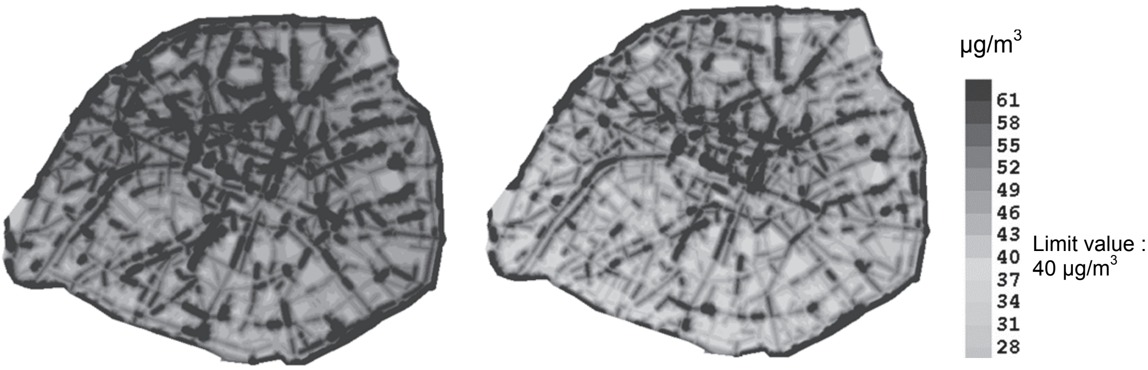

Figure 4: Maps of NO_2 annual average levels in Paris in 2002 (left) and 2012 (right).

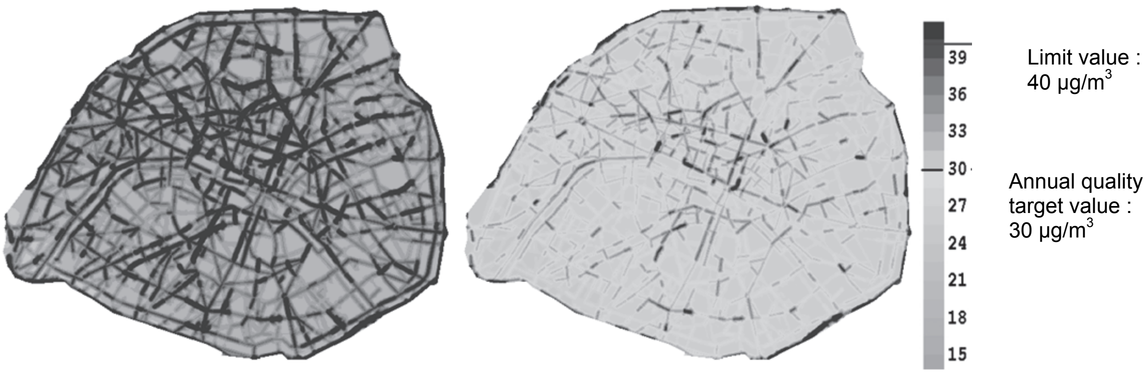

Figure 5: Maps of PM10 annual average levels in Paris in 2002 (left) and 2012 (right).

Combining these maps with detailed population data (population 2006, INSEE, published on January 1, 2009) enables to assess the exposure of the Parisian population. Concerning nitrogen dioxide, the Parisian population exposed to concentrations above the 40 µg/m3 threshold changed a little between 2002 and 2012, as shown in Figure 6: a gain of only 75 000 people was recorded (3% of the population of Paris) for which NO_2 concentrations are below the limit value in 2012 compared to the situation in 2002. Conversely, lower concentrations in ten years lead to a significant drop in the number of Parisians subject to higher levels. Thus, if in 2002 nearly 1.8 million Parisians (80% of the population) are exposed to concentrations above 50 µg/m3, it is almost twice less in 2012 (45%, nearly one million inhabitants) who are exposed to such levels of NO_2. Despite the decrease in annual concentrations of nitrogen dioxide between 2002 and 2012, the Parisian population is still heavily exposed to levels above the limit value.

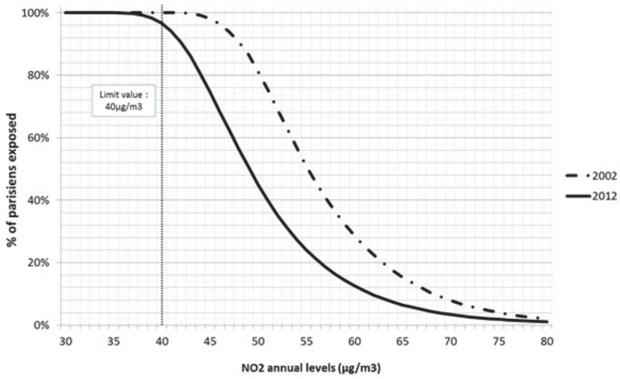

Figure 6: Percentage of the exposed population as a function of NO_2 annual levels.

In contrast, lower concentrations of PM10 between 2002 and 2012 (see Figure 5) have strongly influenced the population exposure (see Figure 7). In 2002, 21% of the population (over 450,000 inhabitants) is above the limit value of 40 µg/m3 and the entire population of Paris is exposed to higher levels than the annual quality target (30 µg/m3). Ten years later, only 1% of Parisians, mostly located close to major roads, under the direct influence of traffic emissions, are exposed to higher levels than this limit value. In addition, in 2012, 78% of Parisians live in areas where levels of PM10 are below the quality target.

Note that in this study, changes in levels of PM10 compared to the daily limit value could not be calculated. In 2012, 2.4 million people in Ile-de-France are subject to exceedances of this standard.

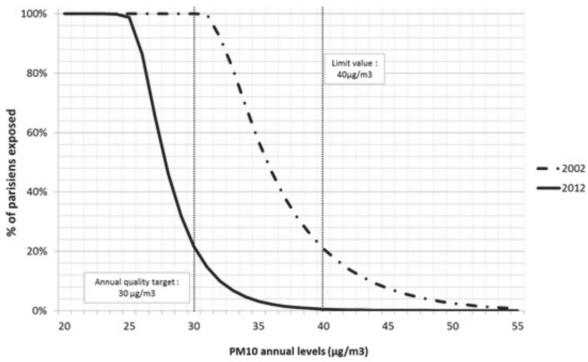

Figure 7: Percentage of the exposed population as a function of PM10 annual levels.

For 10 years, PM2.5 particles concentrations have also significantly decreased. Less and less people are exposed to high levels (> 25 µg/m3, the 2015 limit): 42% of the population (900,000 people) in 2002 and only 1% of Parisians in 2012. However, despite lower levels of PM2.5, the quality target for this pollutant (10 µg/m3) is still largely exceeded in Paris (as in all of the Ile-de-France area).

Comparison with measures from Airparif network: comparing the results of the study to observations on the Parisian background stations from Airparif measurement network throughout 2002 - 2012 (see Table 1), a decrease of 20 % is observed for NO_2 concentrations on average over the four stations. Close to road traffic, there is a smaller decrease over the stations located Central Paris between 3% (Place V. Basch) and 11% (Rue Bonaparte). On the Ring Road, up to Porte d'Auteuil, an increase of 15% was recorded.

Table 1: Evolution of annual concentrations of nitrogen dioxide and particles measured by Airparif network between 2002 and 2012.

Station	Type of station	NO_2	PM10
Paris 7ème	UB	-20%	ND
Paris 12ème	UB	-20%	ND
Paris 13ème	UB	-26%	ND
Paris 18ème	UB	-15%	-20%
Avenue des Champs-Elysées	T	-7%	ND
Rue Bonaparte	T	-11%	ND
Boulevard Périphérique Auteuil	T	15%	-5%
Quai des Célestins*	T	-17%	ND
Place Victor Basch	T	-3%	-21%

* Modification of the axis with the implementation of a bike lane.

The differences between modeled and observed trends can be explained: the contribution of background levels to the concentrations are different depending on axes: a reduction of background concentrations has less impact on the evolution of pollutant concentrations on the axes in which the influence of road traffic is greater. Similarly, changes in technology and fleet have different influence depending on the axes (rates of diesel, LDVs, HDVs) ...).

With regards to PM10, the exercise is more difficult due to a change of measurement method in 2007 and a smaller number of measurement points covering the Île-de-France in 2002 and 2012. A decrease of 20% was recorded at background station (Paris 18th) and close to traffic station (Place V. Basch) in 2012 compared to 2002. On the ring road, a limited decrease of 5% was recorded. Explanations of differences in evolution of $NO_{2,}$ close to traffic, also apply to PM10.

Ranking the parameters that affect air quality in Paris

The objective of the second part of the study is to quantify the impact of each factor influencing emissions (NOx, particulates and CO2), concentrations (NO_2 and particles) and exposure indicators. The following parameters are studied:
- Evolution of traffic (number and speed of vehicles),
- Composition of vehicle fleet, composition of technological park,
- Primary NO_2 exhaust (ratio NO_2/NOx),
- Background concentrations, reflecting the overall evolution of concentrations in Paris due to the evolution of emissions at different scales (local, regional, international).

The three first parameters affect emissions and therefore concentrations and exposure indicators, while the last two ones potentially influence directly concentrations and exposure indicators.

From the base case 2012, the following scenarios were considered:

Table 2: Description of the scenarios.

Scenario name	Description
Traffic 2002	Impact of changes in the traffic between 2002 and 2012: decrease number and average speed of vehicles
Vehicle fleet 2002	Impact of the composition of vehicle fleet: decline in the share of PCs for the benefit of LDVs and 2Ws
Standards 2002	Impact of the composition of technological park regarding "Euro" standards only: fleet modernization
G / D rate 2002	Impact of the composition of technological park as regards the rate of dieselization only: more diesel powered PCs and less gasoline PCs
Technological Park (standards + G / D) 2002	Impact of the composition of technological park, all effects together: "Euro" standards and dieselization of PCs
Background 2002	The effect of background levels: lower background levels for 10 years in Paris

The following tables summarize the main results regarding the contribution of each of the parameters to the evolution of pollutant emissions and exposure indicators between 2002 and 2012.

Table 3: Impact on emissions of various parameters.

Emissions between 2002 and 2012	NOx	PM10	CO_2
Traffic 2002	-11%	-9%	-10%
Vehicle fleet 2002	+3%	+6%	+4%
Standards 2002	-24%	-45%	-5%
G / D rate 2002	+11%	+13%	-2%
Technological Park (standards + G / D) 2002	-26%	-35%	-6%
Overall evolution due to all parameters	-30%	-35%	-13%

Table 4 presents the main results regarding the contribution of the different parameters to 2002-2012 evolution of the number of people exposed above annual regulatory thresholds. High resolution 2006 population is used for 2002 as for 2012; in this study, the number of people exposed is directly linked with the evolution of concentrations.

Table 4: Impact on exposure indicators of the various parameters: changes - all factors combined - from 2002 to 2012 of the number of people exposed above thresholds (number and %); influence of the factors on the evolution from 2002 to 2012 (number of inhabitants, in thousands).

Exposure indicators between 2002 and 2012	NO_2 Threshold: limit value 40 µg/m3	PM10 Threshold: quality objective 30 µg/m3	PM2.5 Threshold: target value 20 µg/m3
Traffic 2002	-24	-170	-157
Vehicle fleet 2002	+2	+42	+38
Standards 2002	+22	-561	-614
G / D rate 2002	+57	+97	+92
Technological Park (standards + G / D) 2002	+35	-396	-428
Overall evolution due to all parameters	-74 (-3%)	-1703 (-78%)	-1878 (-86%)

Note: The effect of each factor cannot be added to obtain the overall effect.

For PM10, only the annual regulation could be taken into account when assessing the impact of the parameters.

The evolution of background levels has the most significant effects on air quality and exposure indicators with a significant impact on the number of people exposed above standards, whether for NO_2, PM10 or PM2.5.

Indeed, 1.7 million Parisians, a gain of over 75%, are no longer exposed to greater values than the quality objective for PM10 (30 µg/m3) due to lower background levels, all other things being equal (lower background levels integrate lower emissions from all sectors, including road traffic; thus, this parameter is not independent of the others).

Between 2002 and 2012, the evolution of traffic (decrease in number and speed of vehicles) resulted in a gain of 10% of emissions of all compounds, including CO_2. The reduction in traffic has also had a positive impact on the concentrations of particles and the number of people exposed: a gain of about 170,000 Parisians, are no longer exposed to greater values than the quality objective for PM10 due to traffic changes between 2002 and 2012.

The impact is less important with regards to the population exposed to NO_2: the effect on the number of people exposed to NO_2 levels above the limit value (40 µg/m^3) is limited with a gain of only 24,000 Paris, less than 1% of the total population of the capital. The impact is greater if we consider a higher threshold: less Parisians are exposed to high values due to the decrease in traffic between 2002 and 2012, 15% of them (315,000 people) are no longer exposed to greater values than 50 µg/m^3.

Modernization of the technological park has had a very positive effect on emissions. The replacement of vehicles between 2002 and 2012 led to a reduction in emissions of all pollutants. This effect is however very low for CO2.

Regarding concentrations of PM10 and PM2.5, about 560,000 Parisians no longer exposed to an exceedance of the quality objective for PM10 (615,000 Parisians no longer exposed to an exceedance of the target value for PM2.5) due to the modernization of vehicles.

However, for NO_2, a negative impact on air quality is observed: despite a 24% gain on NOx emissions, NO_2 /NOx ratio increases due to new diesel vehicles emitting a higher share of NO_2 in NOx emissions than older vehicles (including vehicles with particulate filters based on oxidation catalysis).

Dieselization of the park between 2002 and 2012 had a negative effect on emissions of NOx and particles. In contrast, CO2 emissions are somewhat reduced, since the consumption of a diesel vehicle is smaller than a gasoline vehicle.
This dieselization of the park also led to a significant negative effect on air quality with an increase in the number of people exposed to values exceeding regulatory standards: taking into account this parameter only, nearly 100,000 Parisians more are exposed to values exceeding the quality objective for PM10 and 57,000 Parisians more are exposed to values exceeding the limit value for NO_2 (see Figure 8). Indeed, diesel vehicles emit more nitrogen oxides than petrol vehicles of the same standard and a higher share of NO_2 in NOx emissions; they also emit more particles.

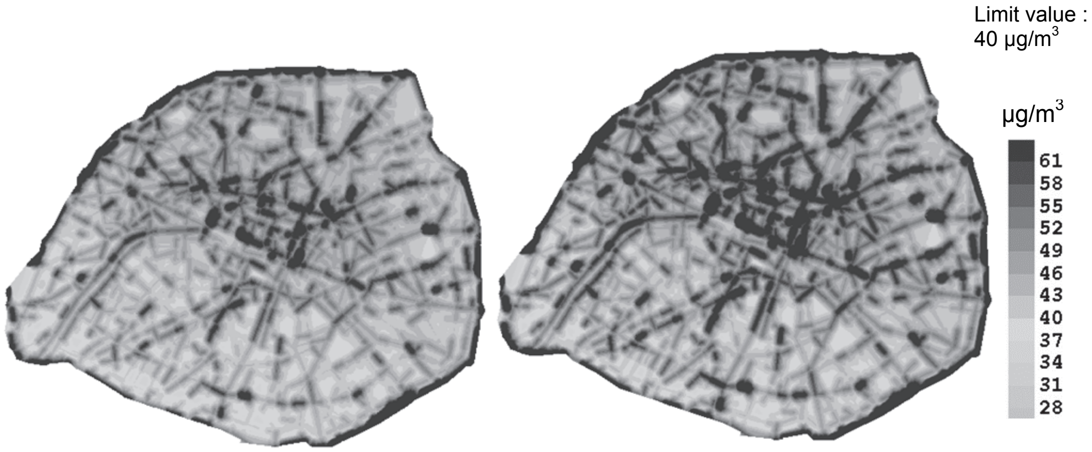

Figure 8: Maps of NO_2 annual average levels in Paris in 2012 with (left) and without (right) E/D scenario.

All effects together, the evolution of the technological park from 2002 to 2012 (modernization and dieselization) led to a significant reduction in NOx emissions (-26%) and particulate matter (-40 to -35%) and a slight decrease in CO_2 emissions.

This scenario also generates a significant positive effect on the concentrations of particles with nearly 400,000 Parisians no longer exposed to exceedances of the PM10quality target, a gain of 45%. Conversely, a negative impact on the levels of NO_2 should be noted despite the decline in NOx emissions. This is explained by the NO_2/NOx ratio which increases with the latest diesel vehicles.

Finally, the evolution of the fleet between 2002 and 2012 generated an increase - however limited – of all pollutants emissions due to a higher share of LDVs and HDVs on the ring road in 2012 than in 2002. This leads to a very small increase in the population exposed to NO_2 and PM10 between 2002 and 2012.

Figures 9 and 10 summarize the evolution of the number of Parisians exposed to annual levels of nitrogen dioxide and PM10 between 2002 and 2012 under the different scenarios.

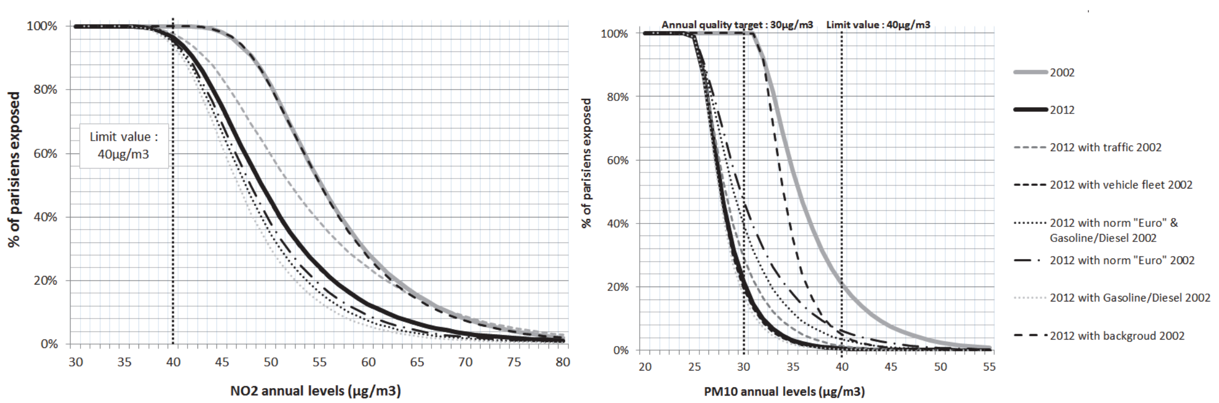

Figure 9: Percentage of the exposed population as a function of NO_2 (left) and PM10 (right) annual levels for each scenario.

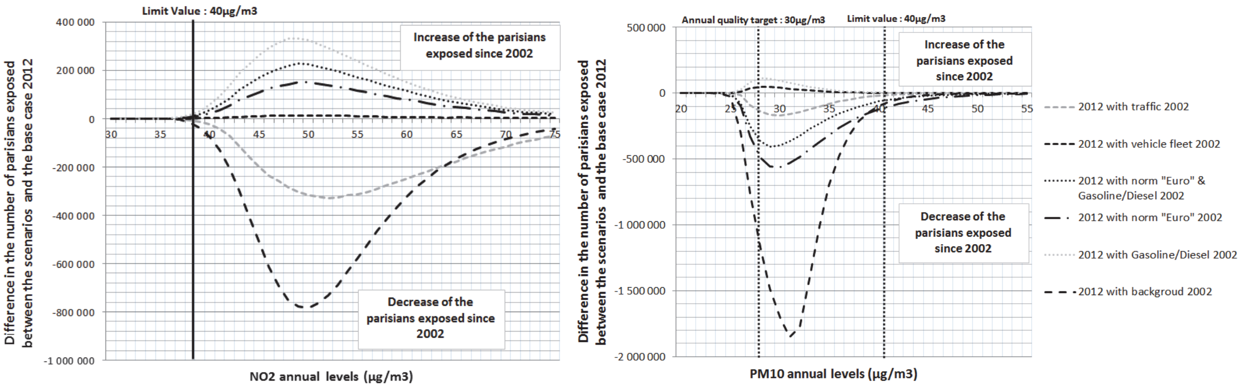

Figure 10: Difference in the number of exposed people as a function of NO_2 (left) and PM10 (right) annual levels between scenarios and base case 2012.

In summary, the order of the first three factors that led to the decline of pollution on Paris over the last ten years is as follows: first, the decline of background concentrations resulting from all measures to reduce emissions from all sectors of polluting activities; then, the technological evolution of vehicles but with a negative effect on NO_2 due to the strong increase in dieselization; finally, traffic reduction in Paris.

Conclusion

The study of the evolution of air quality in Paris between 2002 and 2012 showed that, while levels in the ambient air are still higher in Paris in 2012 than regulatory values for nitrogen dioxide and PM10 and PM2.5, significant improvements in air quality have occurred during the last 10 years.

For NO_2, the improvements are not very sensitive as regards population exposed to levels above the regulatory limit (40 µg/m^3). Only 3% of Parisians submitted to such levels in 2002 are no longer exposed in 2012. However, a huge improvement occurred for populations exposed to higher levels: 80% of Parisians were exposed to levels above 50 µg/m^3, this percentage is reduced to 45% in 2012.

For PM10, a decrease of 78% of people exposed to levels above the quality objective (30 µg/µm^3 annual average) is evaluated. Nevertheless, it is important to consider that the most stringent regulatory value for PM10 is the daily limit value (50 µg/m^3 not to be exceeded more than 35 days per year); only the changes in annual average could be evaluated in this study. In 2012, 1.1 million Parisians are exposed to exceedances of this daily limit value.

Significant drops in background levels, away from specific sources of emissions such as road traffic in particular, are attributable to the reduction of emissions in all sectors (traffic, heating, industrial emissions , ...). Emission reduction is due to local, regional and national or European measures. Reductions in emissions from road traffic in Paris contribute to the overall drop. These decreases in background levels appear to be the most influential parameter on the downward trend in concentrations in Paris between 2002 and 2012.

The traffic decline (-15% over the period) has a positive impact on - decreases - emissions of all pollutants and concentrations, albeit with reports on secondary axes and a decrease in the vehicle speed of about 2 km/h in Paris (from 19 km/h to 17 km/h). For Parisians, these measures have helped 24,000 people with regards to nitrogen dioxide levels and 170,000 for PM10, no longer be exposed to levels beyond the annual thresholds (1% of Parisians for NO_2, 8% for the particles).

The effect of modernizing the fleet with latest Euros standards is not so clear: it is very positive for particles since it has enabled 26% of Parisians to no longer be exposed beyond the quality objective. However, for nitrogen dioxide, there was a slight deterioration for 1% of Parisians. Euros standards have indeed essentially allowed emissions of nitrogen oxides and particulates to fall, but not nitrogen dioxide emitted in greater proportion by the recent diesel vehicles.

However, dieselization of private vehicles fleet had a negative impact, for nitrogen dioxide and, to a lesser extent, for particles emissions, concentrations and exposure indicators. Diesel cars emit at least twice as much nitrogen oxides than petrol vehicle of equivalent Euro standard on an urban route.

The effect on emissions of the green house gas carbon dioxide (CO2) was less marked than for air pollutants NO2 and PM10 (-13%). For this compound, the reduction in emissions is mainly due to the traffic and upgrading vehicles.

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