Aphekom

Improving Knowledge and Communication for Decision Making on Air Pollution and Health in Europe

Local city report

Brussels-Capital

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Acronyms

Aphekom: Improving Knowledge and Communication for Decision Making on Air Pollution and Health in Europe

HIA: health impact assessment

O3: ozone

PM10: particulate matter with an aerodynamic diameter <10 µm

PM2.5: particulate matter with an aerodynamic diameter <2.5 µm

Introduction

Much has been done in recent years in European cities to reduce air pollution and its harmful effects on health. Yet gaps remain in stakeholders' knowledge and understanding of this continuing threat that hamper the planning and implementation of measures to protect public health more effectively.

Sixty Aphekom scientists have therefore worked for nearly 3 years in 25 cities across Europe to provide new information and tools that enable decision makers to set more effective European, national and local policies; health professionals to better advise vulnerable individuals; and all individuals to better protect their health.

Ultimately, through this work the Aphekom project hopes to contribute to reducing both air pollution and its impact on health and well being across European cities.

Chapter 1. Standardised HIA in 25 Aphekom cities

Health impact assessments have been used to analyze the impact of improving air quality on a given population's health. Using standardised HIA methods, the preceding Apheis project (1) (www.apheis.org) showed that large health benefits could be obtained by reducing PM levels in 26 European cities totalling more than 40 million inhabitants (2;3). Apheis thus confirmed that, despite reductions in air pollution since the 1990s, the public health burden of air pollution remains of concern in Europe.

<u>Results of previous similar studies</u>:

Previous health impact assessments of air pollution have been performed in the Brussels-Capital Region within the framework of the European Apheis and Enhis1 projects. Those assessments dealt with the years 2001 and 2004. The same methodology was applied in three Belgian cities (Antwerp, Brussels-Capital and Liege) for the year 2004 in the framework of the Belgian NEHAP (National Environment and Health Action Plan). The atmospheric pollution was assessed via the exposures to particulate matter (PM_{10}) and ozone. The Enhis1 project targeted infants and children.

The health impact assessments were similar for both years. The avoidable mortality related to PM_{10} exposure exceeding the average annual concentration of 20µg/m^3, accounted for approximately 5,6% of the total mortality, for the reference year of 2004 in the 3 Belgian cities. The health benefits of the reduction to 20µg/m^3 for sub-acute exposure (1 month) were double of those of acute exposure (1 day), whether chronic exposure (1 year) leads to greater health benefits.

In Brussels-Capital, if the daily outdoor concentration of PM_{10} is reduced to 20µg/m^3, 66 premature deaths including 37 cardiovascular and 17 respiratory deaths could be prevented annually if the impact is only estimated over a very short term. The short-term impact cumulated over 40 days, would be more than twice as great, totalling 134 premature deaths prevented annually, including 80 cardiovascular and 56 respiratory deaths. And the long-term impact would be even higher, totalling 432 premature deaths prevented annually. The primary risk groups are newborns and elderly.

A reduction of the daily concentration of PM_{10} to a value of 20µg/m^3 would prevent between 11,8 and 7 per 100.000 post-neonatal death in 2001 and 2004. All other things being equal, those numbers would represent 1,12 post-neonatal prevented death in 2004. The large variation has to be explained both by exposure differences and the very low number of post-neonatal mortality, knowing that infant mortality in Belgium is one of the lowest in the world. Regarding hospital admissions, reducing PM_{10} daily mean concentrations to 20µg/m^3 would prevent 221 respiratory admissions of those 21 of children under 15 year of age and 88 cardiac hospital admissions, in 2004.

With regard to ozone (O_3) exposure and short-term effects in summer, each reduction of 10µg/m^3 in the maximum 8hour moving average concentration would prevent respectively for 2001 and 2004, 14 and 13,7 deaths per year in the general population, among those 7,9 and 7,5 would be from cardiovascular diseases and 6 and 5,8 from respiratory causes. In terms of hospital admissions respectively for 2001 and 2004, this would represent 0,42 and 2,67 respiratory admissions in the adult population and 7,23 and 10,8 in the population over 64 years.

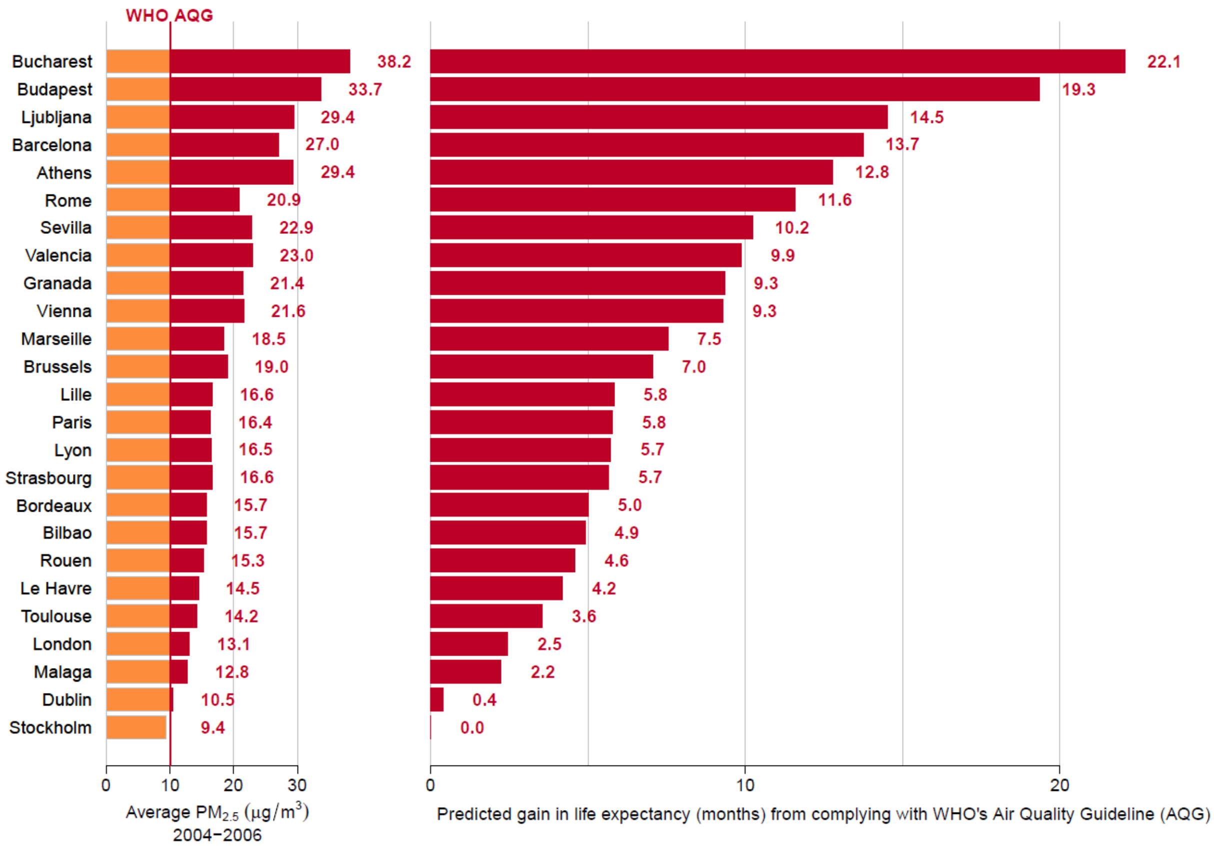
Building on the experience gained in the earlier Apheis project, Aphekom conducted a standardised HIA of urban air pollution in the 25 Aphekom cities totalling nearly 39 million inhabitants: Athens, Barcelona, Bilbao, Bordeaux, Brussels-Capital, Bucharest, Budapest, Dublin, Granada, Le Havre, Lille, Ljubljana, London, Lyon, Malaga, Marseille, Paris, Rome, Rouen, Seville, Stockholm, Strasbourg, Toulouse, Valencia and Vienna. In each participating centre, the project analysed the short-term impacts of ozone and PM_{10} on mortality and morbidity, as well as the long-term impacts of $PM_{2.5}$ on mortality and life expectancy in populations 30 years of age and older.

This work shows that a decrease to 10 micrograms/cubic metre of long-term exposure to $PM_{2.5}$ fine particles (WHO's annual air-quality guideline) could add up to 22 months of life expectancy for persons 30 years of age and older, depending on the city and its average level of $PM_{2.5}$.

Hence, exceeding the WHO air-quality guideline on $PM_{2.5}$ leads to a burden on mortality of nearly 19,000 deaths per annum, more than 15,000 of which are caused by cardiovascular diseases.

Aphekom also determined that the monetary health benefits from complying with the WHO guideline would total some €31.5 billion annually, including savings on health expenditures, absenteeism and intangible costs such as well being, life expectancy and quality of life.

Predicted average gain in life expectancy (months) for persons 30 years of age in 25 Aphekom cities for a decrease in average annual level of $PM_{2.5}$ to 10 µg/m^3 (WHO's Air Quality Guideline)



1.1. Description of the study area for Brussels-Capital

The study area has been defined accordingly to the WP5 guidelines. It also corresponds to the “air quality zone” as prescribed for the EU Directive on air quality (2008/50/CE). It is the same as for the previous health impact assessments performed during the Apheis, Enhis1 and NEHAP exercises. The specificity of Brussels-Capital is being both an urban area and a Region having responsibilities in the transcription of EU directives in Regional laws. The study area includes the whole territory.

The Aphekom project has defined the study area so that data from local air-quality monitoring can provide a good estimate of the average exposure of the population in the study area, taking into account local land use, daily commuting and meteorology.

The study area covers the Capital Region of Brussels. It includes 19 local authorities for a total territory of 161,4 km^2. As local authorities are heterogeneous in terms of population, housing and many other parameters, they are divided into 724 statistical quarters, those being reunited to form 118 homogeneous neighbourhoods/districts (see Figure 1) that do not always coincide with the local authorities boundaries. The city presents numerous local centres linked to business activities, commercial or residential and recreational areas. The city is organised in a radio-concentric schema with 3 zones (the heart of the city called the “Pentagon”, a first belt of dense historical quarters delimited by boulevards and second belt more residential).

The population living in the study area is estimated to 1million inhabitants. The population density differs widely between local authorities with respect to population characteristics, housing and socio-economic status. The region has no heavy industries, it concentrates a large number of administrations and state institutions due to its activities as national, regional and European capital, transportation infrastructures, and one international airport is located at its outskirts.

The available space per inhabitant is larger than most of the other European Capitals. A large part of the neighbourhoods consists in old houses of 3 stories, relatively narrows and long but organised around central green spaces as “inner green islands”, some having been transformed into storage or small workshops. That spatial urban organisation was common during the 1rst century for Belgian and northern France cities. Brussels-Capital has also numerous art deco and modern large buildings. Industrial spaces have been transformed into lofts and in business quarters classical buildings are next to administrative towers. It is also one of the most cosmopolitan and richest cities.

Brussels-Capital is one of the greenest Capitals of Europe. Numerous green spaces, park areas are within the city boundaries. Many “inner islands” consist in green gardens. The proportion of green spaces is very high it accounts for 53% but it is not equally distributed.

The wider “agglomeration” defined by the employment basin would spill out Brussels-Capital; it would include 2,7million inhabitant and extend up to a large part of both Walloon and Flemish Brabant provinces. The urbanised area is even larger and reaches a triangular zone between Brussels, Antwerp and Gent. It would include about 4,4 million inhabitants.

Figure 1 – Map of the study area – Brussels-Capital

Climatology

A rather broken topography where 2 basins are separated by a hill still reminds the important water context of Brussels-Capital developed on swamp. The large valley of the Senne crossing the city from south west to north, reaches the altitude of 10-20m (from sea level) while the narrow valley of the Woluwe located on the east side of the city, climbs to 20-30m. The hill culminates at 100m.

Brussels-Capital shows a temperate oceanic climate as most of the west part of Belgium. The proximity of the Atlantic Ocean and the Gulf Stream regulate the weather and influence it with humid but moderate zones coming from the ocean and also dry zones (hot in summer and cold in winter) coming from the inner part of the European continent.

Major winds come from the South West but when seasons change the occurrence of North East and South West winds is equally important over Brussels-Capital. Major winds go through the valleys, they usually reach 20km/sec but we have had several storms over the seasons. North East winds come from poles, cold and dry, while South West winds, alizés bring warm temperatures. South wind is dry while West is wet. Winds influence the mixing of air pollutants. Dispersion of pollutants or horizontal mixing is directly related to the wind regime (direction, origin and speed). Fresh air insures the dilution and eventually the evacuation of the local pollution. Winds for the west sectors with a higher force would insure a greater dilution while winds from the east sectors, slightly lower would insure a less good mixing. Vertical dispersion or mixing of the concentrations is of importance in Brussels-Capital. The combination of the reached altitude of the mixing layer and the weather conditions could result in the stagnation of a pollution cloud on Brussels-Capital. It is when we observe the phenomenon of temperature inversion and pollution accumulates underneath a colder temperature layer. That phenomenon happens frequently over Brussels during winters and summers and lead to “pollution episodes”.

Temperature maxima were observed in Uccle (South of Brussels-Capital) in 1947 for the hottest day (38,8℃) and in 1881 for the coldest (-21,1℃).

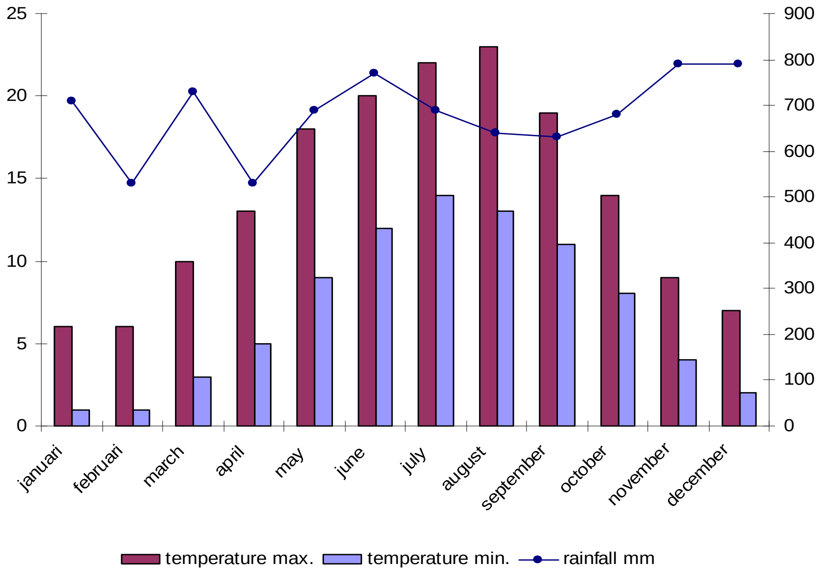


Figure 2 – Evolution of monthly temperatures and rainfall in Brussels-Capital (over the last 100 years)

The four seasons are well defined, the mean "normal" annual temperatures reaches 9,8℃ and rainfall lasts for about 200 days per year in Brussels-Capital. The variations during the study period are described on Table 1.

	2004	2005	2006	"Normal" year
Mean annual temperature (℃)	10,7	11,0	11,0	9,8
Mean max temperature (℃)	14,3	14,8	15,0	13,5
Mean min temperature (℃)	7,0	7,5	8,0	6,3
Mean rainfall (days)	198	200	180	203
Mean rainfall (mm)	914	751	835	780

Table 1 – Evolution of temperatures and rainfall during the study period compared to a "normal" year in Brussels-Capital

Population in the study area

The population living in the study area is estimated to 1million inhabitants. It had been decreasing steadily from the years '70 to the end of the '90s but since the early 2000 it increased regularly. For instance during the study period it evolved from 999.899 inhabitants in 2004, to 1.006.749 in 2005 and 1.018.029 in 2006. At the 1rst of January 2008 it reached 1.048491 inhabitants to which should be added some 17.180 waiting to be registered.

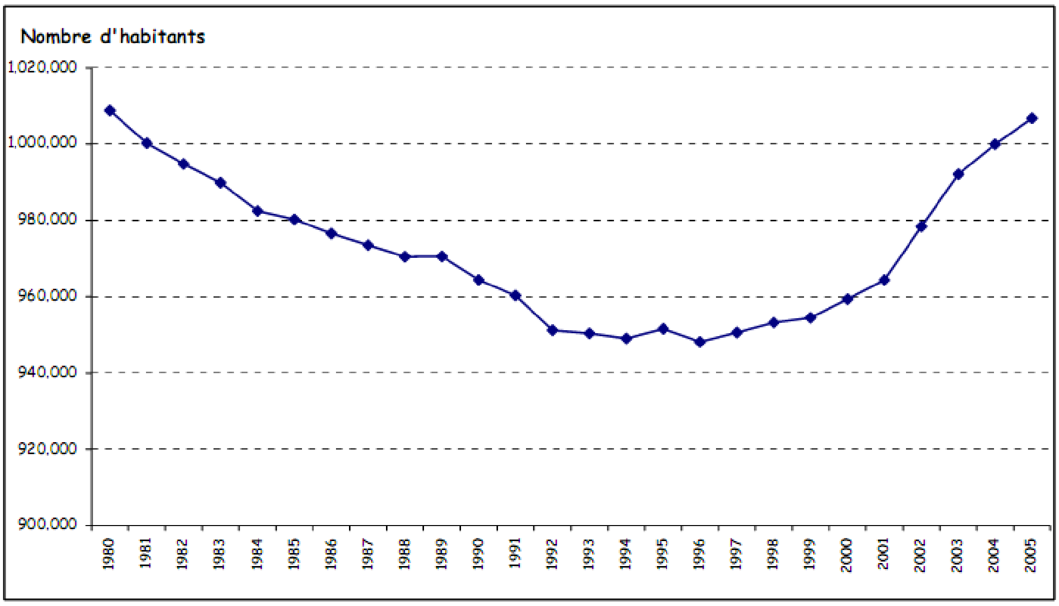


Figure 3 – Evolution of the population of the Brussels-Capital Region from 1980 to 2005 (source ISBA)

Brussels-Capital population is young. The Brussels population structure is a pyramid whose base is enlarging, accounting for the increasing number of children and young adults. The “mean age” for the Brussels population during the study period decreased from 38,07 in 2004, to 37,95 in 2005 and 37,83 in 2006 and it continues since. In Belgium as a whole the “mean age” was for the same period, 39,73 in 2004, 39,87 in 2005 and 39,98 in 2006. The rejuvenating of urban population is widely spread in large agglomeration but Brussels-Capital population “rejuvenation” is steadily observed since 1981. The ratio between women and men varies with age; the male population is slightly larger for the age groups of younger than 20 and between 30 and 50, from 50 on the women proportion increases progressively to get 74% at the age of 85. Life expectation is increasing in Brussels-Capital (in 2006: 76,9 for man and 82,0 for woman) while the difference between man and woman decreases. Birth rate is increasing more than in other regions of Belgium, it is related to he large proportion of young adults. However the mortality rate is decreasing and touches women due to the larger proportion of older women. If we compare the standardized mortality rate of Brussels-Capital to other urban area of Europe for both women and men, it is higher than those of Madrid, Berlin, or Stockholm, and close to those observed in London, Luxembourg or cities in the Netherlands being among the 10 lowest. Influence of the socio-economic parameters and ways of life could explain such differences. (Brussels Health and Social Observatory : Brussels Health Dashboard, 2010)

Brussels-Capital population is multicultural. The proportion of non-Belgian national is increasing for instance it reached 28,1% at the 1rst of January 2008. Two-third of the non-national come from the EU27 member states, among the others Mediterranean nationalities represent a large group.

The population density differs widely between local authorities with respect to population characteristics, housing and socio-economic status. Brussels-Capital is characterized by a significant concentration of poverty in the highly populated districts of central Brussels, known as the poverty crescent (“croissant pauvre”), (lower Saint-Gilles, Cureghem, the Marolles, the south of the pentagon, lower Molenbeek, Laeken, lower Schaerbeek and Saint- Josse-ten-Noode). (Brussels Health and Social Observatory: Social Barometer 2010)

Family structure varies a lot but 1 person’s family accounts for 49% of the population and couples with children reach 21%. In the poverty crescent, there are numerous families with young children. It has unemployment levels of over 25%, rising to more than 40% among young people. The proportion of households receiving welfare benefits is up to 5 times higher than in the rest of the region. Those districts also benefit of a continuous influx of the poorest groups of the population, consisting above all of migrants, legal or illegal. Some of them remain only temporarily other stay longer or definitively.

The employment rate in Brussels-Capital remains below that of the country as a whole, as well as below the European target. Access to employment is more difficult for low-skilled workers and non-European nationals.

Commuting

To work and study in Brussels-Capital are driving forces that explain the large commuting population coming from outside the Region. Commuters (workers and students) come everyday from any other part of Belgium and even from France, Luxembourg or the Netherlands, they represent more than 50% of the employment. In 2008, commuters from Wallonia account for 18,8% while those coming from Flanders account for 33,2%. Brussels residents accounted for 48,1% of the jobs. But among the Brussels residents 1,7% work in Wallonia, the same amount in Flanders and 4,1% work in anther country. Commuting is performed using different modes (car, bike, rail, metro, bus or tramway).

Car transportation is important. In 2008, every day, 370.000 vehicles transported workers, students from home to work in the Brussels-Capital Region. Among those 186.000 entered the territory from outside either Wallonia or Flanders. Daily commuting by car represents halve of the number of personal vehicles moving in Brussels. (Plan IRIS II, Report on the State of the Environment of the Brussels-Capital Region : SEE 2003-2006, Energy balance of the Brussels-Capital Region 2008, 2010).

1.2. Sources of air pollution and exposure data

Sources

Brussels-Capital has no heavy industries, it concentrates a large number of administrations and state institutions due to its activities as national, regional and European capital, transportation infrastructures, and one international airport is located at its outskirts.

Emissions mainly come from transport, heating and a number of minor other miscellaneous sources.

Pollutant	Year	Road (kt)	Heating (energy) (kt)	Industry (energy&process) (kt)	Other sources (incineration of domestic waste) (kt)
SO_2	2005	0.0518	1.3294	0.0033	0.0162
	2006	0.0269	1.1413	0.0033	0.0161
NO_x	2005	3.6610	2.3856	0.0043	0.8843
	2006	3.2521	2.3079	0.0043	0.2561
Primary PM_{10}	2005	0.2739	0.0895	0.0005	0.0329
	2006	0.2431	0.0845	0.0005	0.0014
Primary $PM_{2.5}$	2005	0.2367	0.0864	NA	0.0174
	2006	0.2069	0.0815	NA	0.0014

Table 2 – Main sources of air pollution in Brussels-Capital (in kilotons/year for the years 2005 and 2006) [IBGE, 2010]

The main source of SO_2 is fossil fuels combustion containing sulphur, and in a minor proportion, some industrial processes in Brussels-Capital. The concentrations of SO_2 in ambient air have dramatically decreased since the decrease of the coke production at Marly between 1990 and 1992 leading to a permanent stop in 1993, the increase of natural gas in the consumption patterns for heating, the decrease of the sulphur content of fuels for heating or vehicles and the disappearance of some heavy fuels containing 2-3% of sulphur since 1997, and eventually the upgrade of the domestic waste incinerator with a “smokes cleaning process” in 1999. Never mind further developments of domestic heating systems with wood or coal would need to remain vigilant.

The main source of nitrogen oxides within the study area is road traffic. According to the inventory of emissions for the year 2008, road traffic, together with other mobile sources, represents 47% of the NOx emissions while heating and in particular respectively housing and administrative building heating represents 32% and 13%, Industrial processes being the domestic waste incinerator 3% (IBGE 2010).

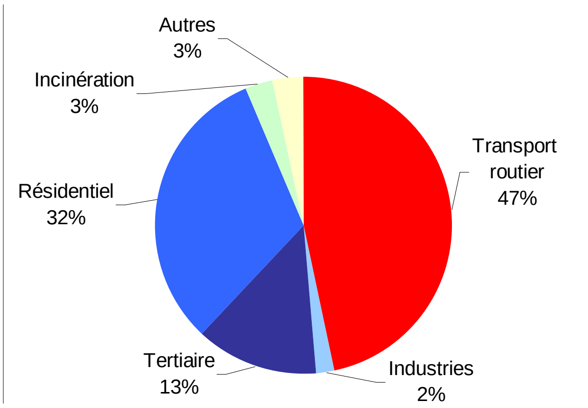


Figure 4 : Sectoral NOx emissions in Brussels-Capital (emission inventories 2008, IBGE 2010).

NOx, resulting of nitrogen oxidation in the air when high temperature combustion occurs, is related to traffic, heating, energy production or chemical processes. Emissions would take the chemical form of NO (90%) and NO_2 (10%). The ratio NO/NO_2 depends on the delicate balances between NO, NO_2, O_2 and O_3 but also VOC (volatile organic carbons). In Brussels-Capital, the total decrease of NOx emissions linked to efforts in the traffic sector (decrease of 65% of emissions related to technical improvements of car combustion) and in adding a filter on the incinerator chimney, has not led to the expected respect of air quality norms for the annual mean of NO_2 (see figure 5). In order to read correctly the Figure 5, we have to remember that Uccle is a background monitoring station while Molenbeek is traffic-related.

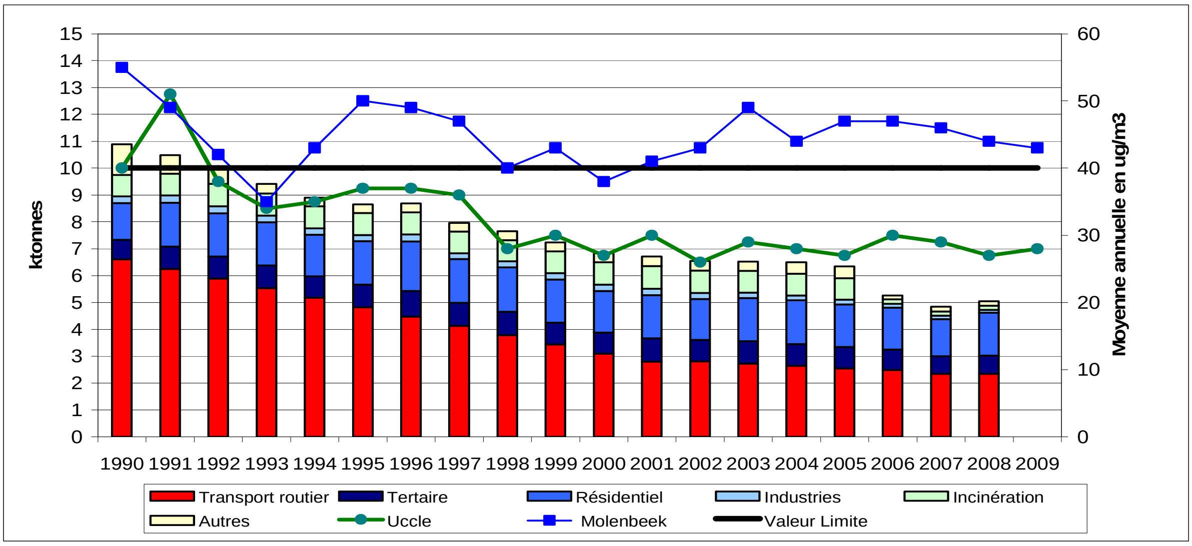
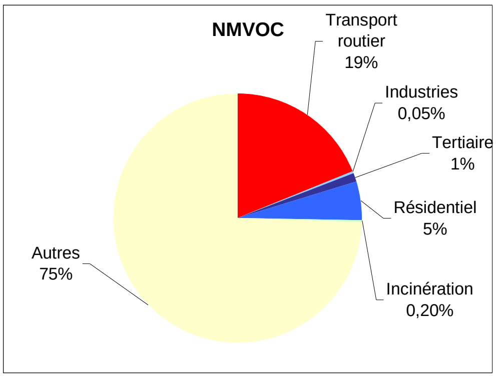


Figure 5 : Temporal evolution of NO_x emissions de NO_x and annual mean concentrations of NO_2 at 2 monitoring stations (Molenbeek trafic station and Uccle background station), from 1990 to 2009, in Brussels-Capital (source IBGE 2010).

Volatile organic carbons emissions have decreased regularly since 1990 on the base of the decrease of traffic emissions related to the “catalyst exhaust” technical development for cars, the decrease of VOC content in fuels while the domestic use of VOC has not significantly decreased. It represents the first source of VOC (38%). The industrial sector showed a decrease in emissions by 30% from 1990 to 2008.



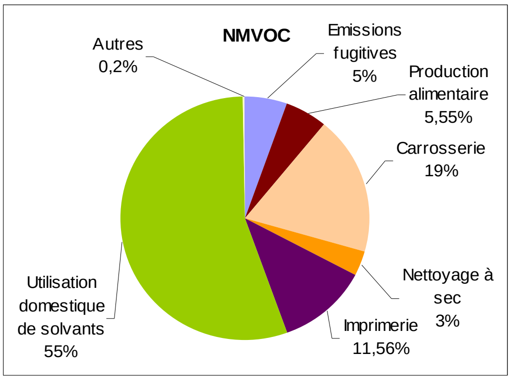


Figure 6 – Sectoral NMVOC emissions in Brussels-Capital (emission inventories 2008, IBGE 2010) left side all sectors and right side detail of « others ».

Particulate matter comes from several sources among those localized or mobile sources related to combustion processes, recombination of gaseous pollutants such as VOC, NO_X, SO_X and NH_3 present in the atmosphere and indirect sources due to pollutants transport and weather conditions. Besides anthropogenic emissions (combustion, traffic, production processes…), major contributions to the total mass concentration of the particulates in the Brussels ambient air are coming from airborne aerosol (formation of secondary particulates) and from the (re)suspension of the coarser PM fraction, particulates with an equivalent diameter between 2.5 and 10 µm. Within particulate matter several size groups are important, it is accepted that smaller particles (0.1-0.01µm) are potentially more toxic.

Analysis of the PM_{10} concentration showed that only about 30% of the total PM_{10} mass concentration in the Brussels urban area is related to the local particulate emissions (Vanderstraeten et al 2009). The traffic sector is the major local source of PM_{10}, 68% of local PM_{10} arise directly from car fuel combustion. Other sources include heating in housing and administrative buildings account for respectively 24% and 6%. Industrial sources contribute to a lesser extend. In some weather conditions PM_{10} might represent 60-70% of the total PM (see results of European day without cars, Report of the State of the Environment of the Brussels-Capital Region: REE2003-2006, reports of days without cars).

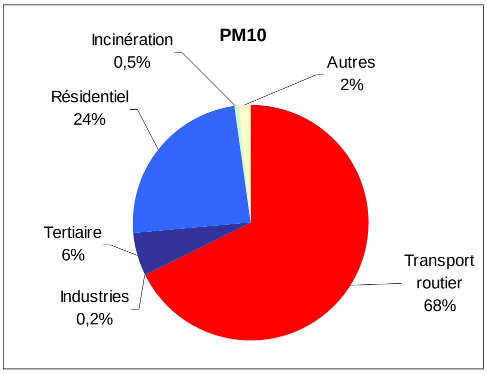


Figure 7 : Sectoral PM10 emissions fine particules (PM10) in Brussels-Capital (based on emission inventories 2008, IBGE 2010).

The evolution of PM_{10} emission since 1990 is substantial; they are due to the definitive stop of the coke production at Marly in 1993. Since 1993, the decrease is linear and represents 50% in 15 years. It is principally related to traffic and technological evolution of motors. Differences winter/summer and weekdays/WE are also noticeable.

The weekend effect is illustrated in Figure 9. It concerns PM_{10} but also NO and NO_2. It shows a slight decrease on Saturdays and a larger decrease on Sundays

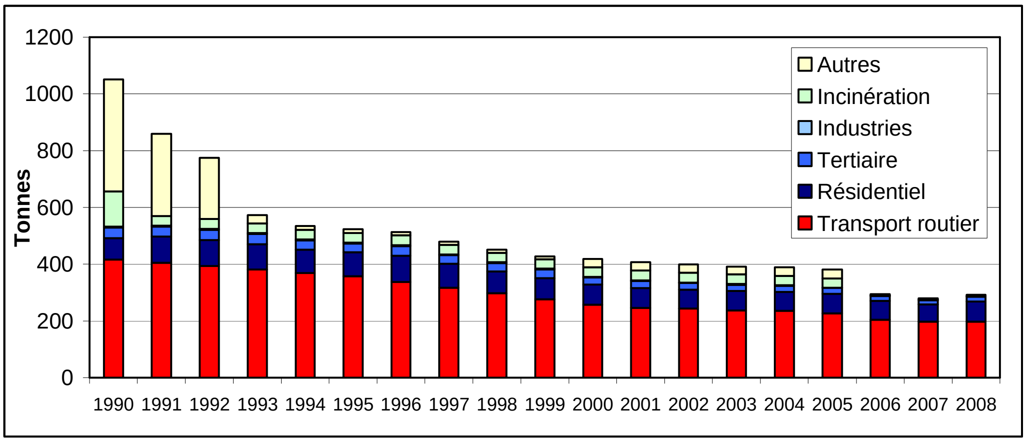


Figure 8: Temporal evolution of PM_{10} emisions by activity (tons) 1990 to 2008 in Brussels-Capital (IBGE 2010)

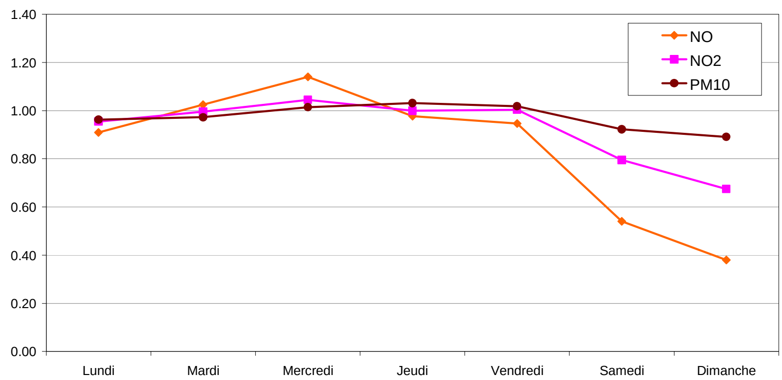


Figure 9 : Daily mean evolution of standardised concentrations of NO_2, NO and PM_{10} (spatial mean for the region) in Brussels-Capital. The period concerns January to March and October to December 2006-2008 at 6 monitoring stations [Vanderstraeten et al., 2007].

Exposure data

Brussels-Capital has a dense network of monitoring stations, it has both telemetric and non-telemetric configuration depending on the monitored pollutants (see Figures 10 and 11). The Research Laboratory on Environment of the Brussels Institute monitors air pollution levels for the Management of the Environment. The telemetric network development has started in 1978 and has been progressively and continuously enlarged. In 1994, there were 6 monitoring stations; since new stations were added progressively to a network of 12 stations. Specific situations are also monitored such as underground parking and tunnels. Measuring methodologies were actualised to monitor more pollutants and be coherent with obligations from EU directives. Tables 3 and 4 summarise the network (typology of monitoring stations and pollutant/methodology) used for the study. The non-telemetric network allows measuring some other parameters (Lead in particulate matter, VOC, PAH, Black Smoke, gaseous SO2, NH3, HCl, HF, heavy metals) to complete the analysis.

Type of Station	Code Measuring Station
Background Urban	B011 - R012
Suburban	B004 - B005 - B006 - MEU1 – E013*
Industrial	N043
Traffic	R001 - R002 - B003 - WOL1

Table 3 – Summary of the typology of monitoring stations of the telemetric network in Brussels-Capital (*E013 does not belong to the Brussels-Capital Region)

Pollutants	Monitoring stations (Date of use)	Methodology used (correction factor = c.f.)
PM_{10}	2 (1998) - 6 (2008)	TEOM + (c.f.=1,47) until 2005, FDMS+TEOM since 2005
PM2.5	1 (1999) – 5 (2008)	TEOM + (c.f.=1,60) until 2006, FDMS+TEOM since 2006
NO_2	2 (1990) – 12 (2008)	Luminescent chemistry
NOx	2 (1990) – 11 (2008)	Luminescent chemistry
SO_2	3 (1990) – 8 (2008)	Fluorescence UV
Ozone O_3	1 (1990) – 7 (2008)	UV absorption

Table 4 – Summary of the pollutants and methodology used in the telemetric network of monitoring stations in Brussels-Capital

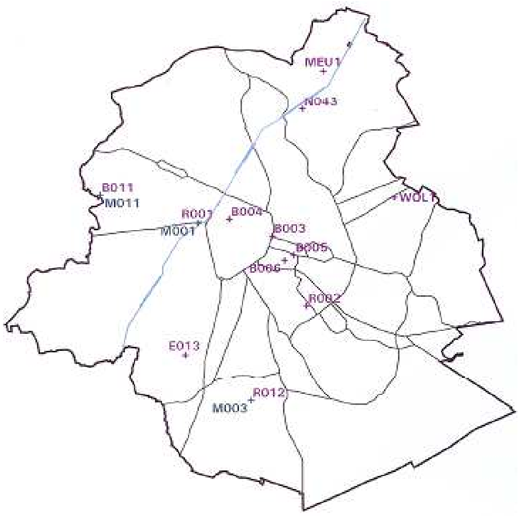


Figure 10

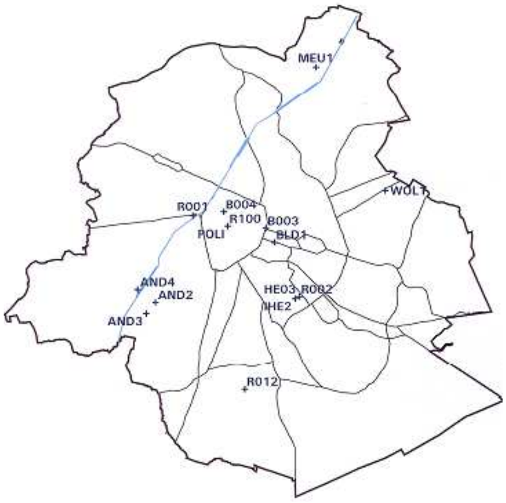


Figure 11

	SO_2	NO	NO_2	NO_x	O_3	CO	PM_{10}	$PM_{2,5}$	P_{Cnt}*	CO_2	BTX**	Hg
R001	X	X	X	X	X	X	X	X				
R002	X	X	X	X		X				X		
B003	X	X	X	X		X				X		
B011	O#	X	X	X	X		X	X				
R012	X	X	X	X	X		X	X		X		
N043	X	X	X	X	X	X	X	X				
WOL1	X	X	X	X	X	X	X		X	X	X	
MEU1	X	X	X	X			X	X				X
B004		X	X	X	X	X						
B005	X	X	X	X	X	X					X	
B006		X	X	X		X						
E013	O#	X	X	X								

Figure 10 – Map of the telemetric network of monitoring stations and list of monitored pollutants in Brussels-Capital – IBGE 2010

	Pb	HMT	SNH	BSM	COV	HPA
R001				X	X	X
R002				X	X	X
B003					X	
B004			X			
R012	X		X	X	X	X
WOL1					X	X
IHE03	X					
MEU1	X	X	X			X
AND3	X	X				

Figure 11 – Map of the non-telemetric network of monitoring stations and list of monitored pollutants in Brussels-Capital – IBGE 2010

Indicators have been calculated from measures at the selected stations.

- Ozone: The daily maximum 8-hour moving averages of each day have been calculated for the whole year.
- PM_{10} and PM2.5: daily exposure indicator has been calculated as the arithmetic mean of the daily concentrations of the stations.

The daily mean levels for ozone, PM_{10} and PM2.5 are summarised on Table 5. Figures 12, 13 and 15 illustrate the variation of the daily mean levels during the 3-year study period. Comparing with air quality data of the year 2001, mean concentrations levels of PM_{10} were slightly higher in 2004 and quite similar concerning ozone.

Pollutant	**Daily mean (µg/m^3)**	**Standard deviation (µg/m^3)**	***5th percentile* (µg/m^3)**	***95th percentile* (µg/m^3)**
Ozone (daily 8h max)	**59**	**33**	**5**	**123**
PM_{10} (daily average)	**26**	**12**	**12**	**50**
PM2.5 (daily average)	**18**	**12**	**4**	**42**

Table 5 – Daily mean levels, standard deviation and 5th and 95th percentiles for air pollutants in Brussels-Capital (2004/01/01 – 2006/12/31)

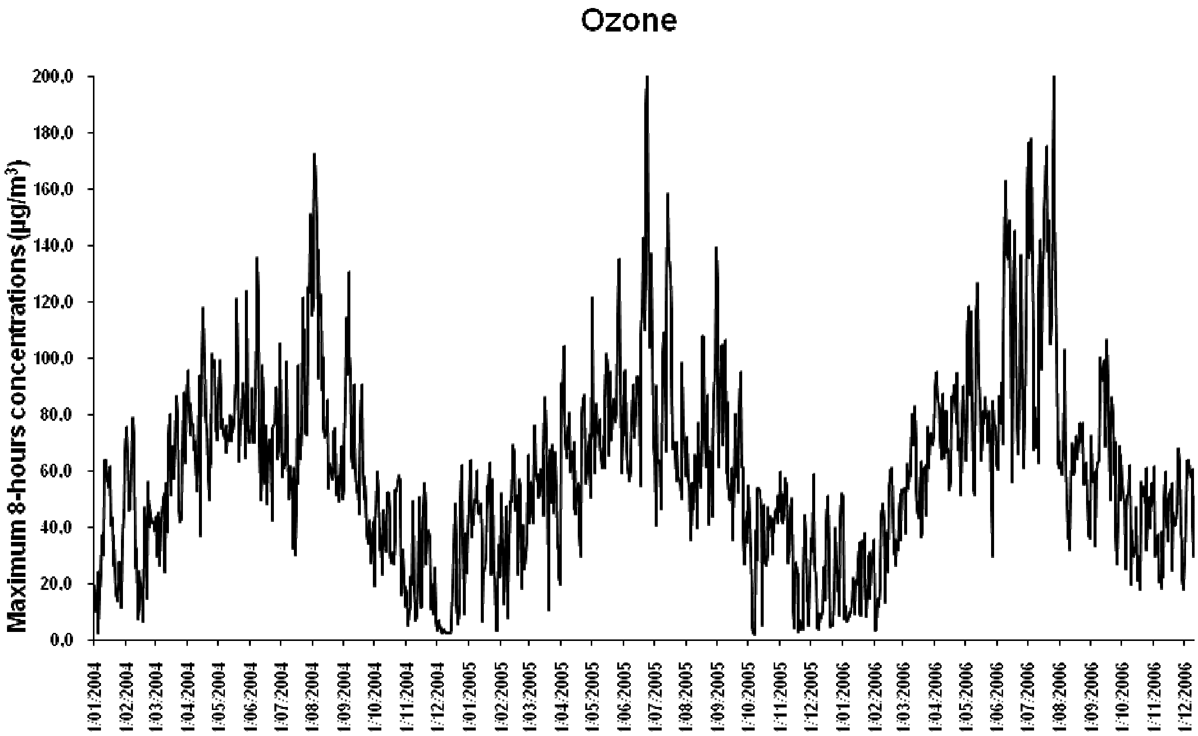


Figure 12 – Ozone concentration in Brussels-Capital

Ozone varies along seasons but there are peaks all along the year. The mean (SD), P5 and P95 of the daily maximum 8-hour moving average concentrations of O3 were, respectively, 59 (33), 5 and 123µg/ m^3 (Table 4 and figure 12). Concerning ozone and following the Directive 2002/03/CE, the daily maximum 8-hour moving average target value for 2010 is that the 120µg/ m^3 value should not to be exceeded on more than 25 days per calendar-year averaged over 3 years. The number of exceeding values was higher than that authorised by the Directive in 2001 for 2 monitoring stations (the reference stations showed exceedances during 26 days). Again in 2003, 4 monitoring stations were concerned and in 2006 concerning 3 monitoring stations. When we calculate the number of exceedances for the averaged year over the years 2004 to 2006 there has not been any monitoring stations over 25 days above 120µg/m^3 in Brussels-Capital. Daily levels of ozone (both 1-hour and 8-hour) show a large variability, but in Brussels-Capital the thresholds limits for population information (180µg/m^3 for 1-hour average) were not overshot.

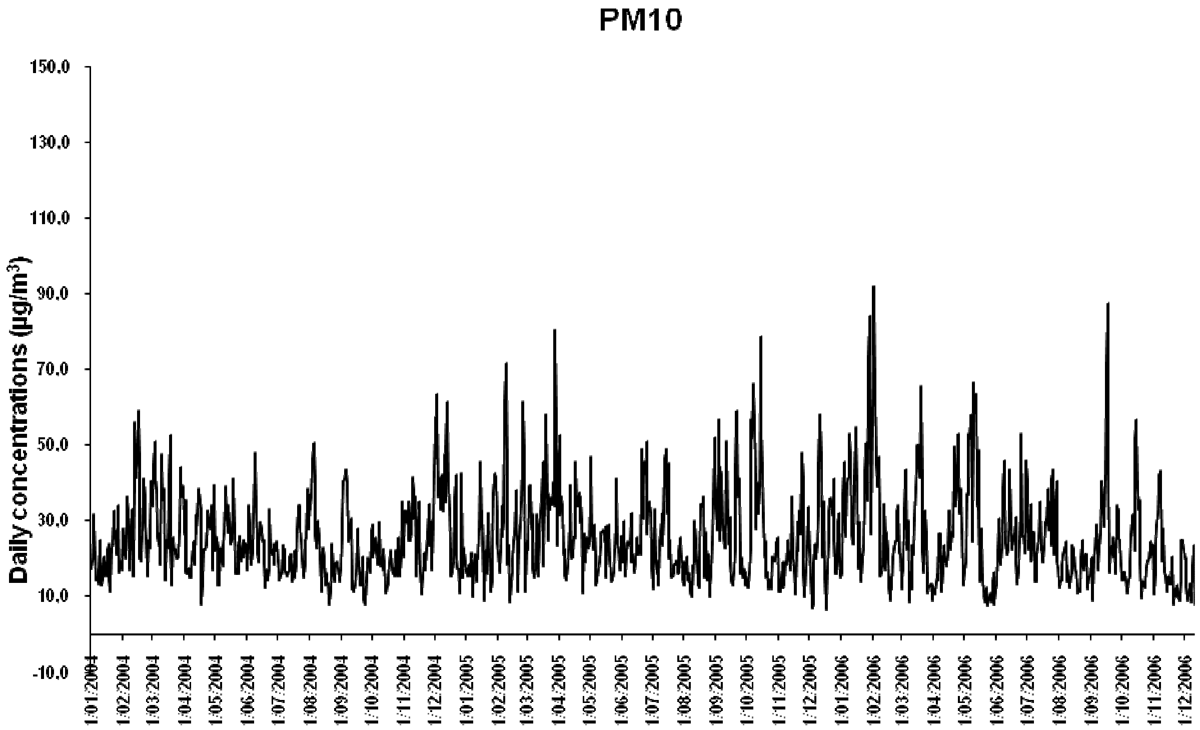


Figure 13 – PM10 concentration in Brussels-Capital

PM10 and PM2.5 do not follow a seasonal pattern but the variation of exposure is important from one day to the next.

The annual mean (SD) of TEOM (corrected) and FDMS+TEOM PM_{10} in Brussels-Capital was 26 (12) µg/m^3, and P5 and P95 of the daily mean values were, respectively, 12 µg/m^3 and 50 µg/m^3. Following limits set in the Directive 1999/30/CE, both TEOM (corrected) and FDMS+TEOM PM_{10} annual mean levels were lower during the study period than the limit value for 2005 (40µg/ m^3) (Table 4 and figure 13). However, both TEOM and corrected annual mean levels were higher than the limit value for 2010 (20µg/ m^3). However, the general tendency of PM_{10} shows a decrease of the mean annual values over the years (Figure 14). Combining results with winds shows that the mean concentrations of PM_{10} are slightly higher when winds come from South East.

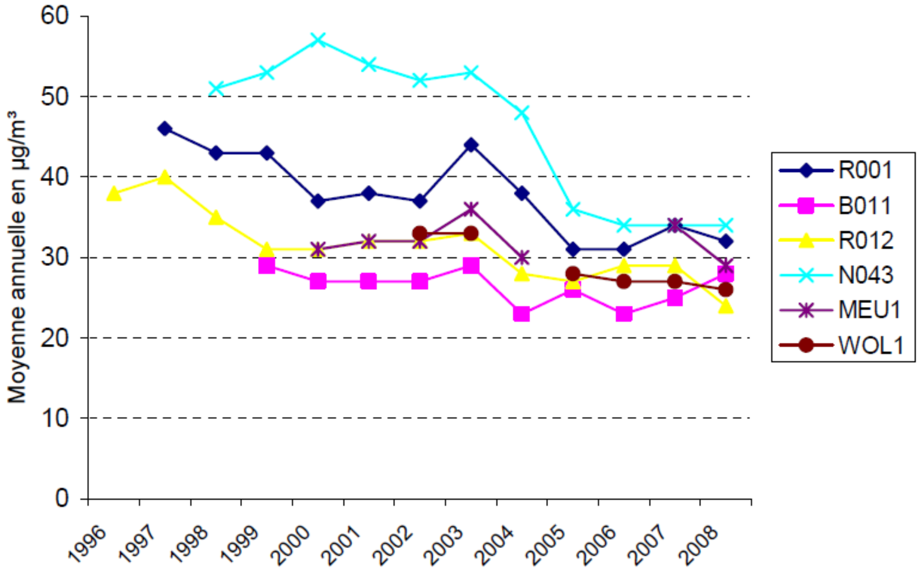


Figure 14 – Evolution of the PM_{10} mean annual concentration at the various monitoring stations of the Brussels-Capital Region over the years 1996 to 2008

The number of exceeding PM_{10} daily mean values (50µg/ m^3) per year was higher during the year 2004 to 2006 than the maximum number allowed since 2005 (35 days) (Directive 2008/50/CE). It evolved from 127 days in 2004, 66 in 2005 and 57 in 2006.

In the Brussels-Capital Region at least 3 different phenomena may lead, separately or by combination, to elevated PM_{10} concentrations and to an increased risk of exceeding the 50µg/m^3 limit value for the daily mean concentration (Vanderstraeten et al 2009).

- Meteorological conditions with poor dispersion, due to a temperature inversion and low wind speed, are a common factor resulting in high concentration levels for different pollutants. These conditions occur mainly during winter.
- A second phenomenon, very important and still largely underestimated, is the formation of secondary aerosol during the period March-April and, to a lesser extent, September-October. The spreading of manure on a large scale, in the surrounding regions, before and after the agricultural season, releases a massive source of ammonia coming from the agricultural fields. At moderate temperature (8-20℃) and high Relative Humidity (80 -90% RH) conditions, a stable secondary aerosol is formed with ammonium nitrate as a main component. In these cases nearly 80 to 90% of the total PM_{10} mass concentration consists of PM2.5, including volatile and/or possibly dissociating components that are mainly present within the PM2.5 fraction. The concentration increases gradually and high PM_{10} concentrations, exceeding the daily limit value, are detected simultaneously over an extended area, much larger than the Brussels-Capital Region. Furthermore the temporal evolution of the PM mass concentration may be quite different from the temporal pattern followed by components that are more directly linked with the local traffic emissions, such as NO and NO_2.
- The third phenomenon, the (re) suspension of the coarser fraction, is linked with the advection of dry air coming from the large sector East. Under these conditions and in the presence of a local source of the coarser fraction, these particulates (2.5 to 10µm) are suspended by a local activity, by the wind and/or by the turbulences created by the traffic. This may lead to the detection of high PM_{10} concentrations at a limited number of sites, situated close to the street or to a local source. In these cases PM2.5 represents only 40 to 50% of the total PM_{10} mass concentration and no volatile or dissociating material is detected. In the Brussels Capital Region, the second limit value for PM_{10}, not more than 35 days with a daily concentration higher than 50µg/m^3, is systematically exceeded at two different sites, the industrial site at the Brussels naval port (N043) and the traffic site (R001 - Molenbeek) located along the industrial and commercial axis. An analysis of the wind direction and classes of relative humidity, corresponding to the exceeding days, makes clear that, for these two sites, the excess of exceeding values is strongly correlated with the presence of dry air coming from the sector East. There is also a strong correlation with the lower classes of

Relative Humidity. The local presence of the coarser fraction is related to the storage and the handling of bulk material for construction purposes.

These comprehensive observations do accentuate the complexity of the PM_{10} problematic and the relative contents of PM_{10} and PM2.5.

The annual mean (SD) of TEOM (corrected) and FDMS+TEOM PM2.5 in Brussels-Capital was 18 (12) µg/m^3, and P5 and P95 of the daily mean values were, respectively, 4 µg/m^3 and 42 µg/m^3 (Table 5 and figure 15). Following limits set in the directive 2008/50/CE in order to protect human health, both TEOM and corrected annual mean levels were lower than the stage1 objective being 25µg/m^3, but it is early to predict the conformity with stage 2 objective being 20µg/m^3 (for 2020).

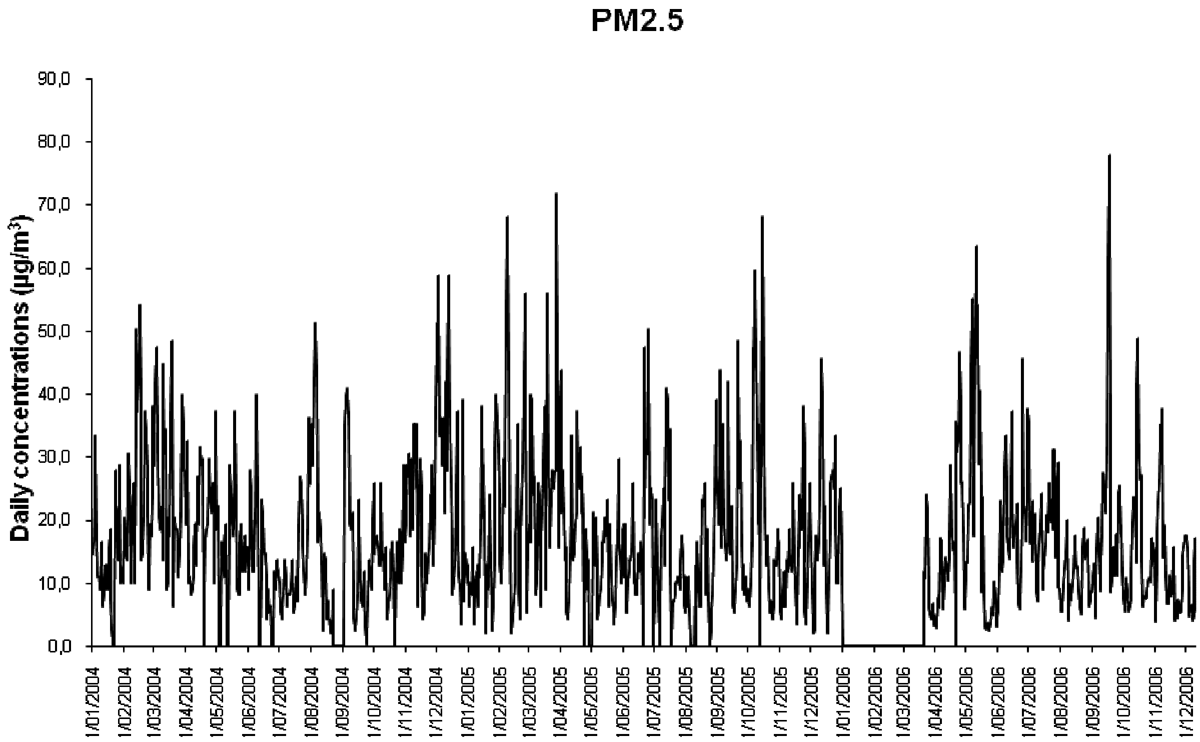


Figure 15 – PM2.5 concentration in Brussels-Capital

1.3. Health data

Mortality data are obtained from death certificates. For each death, a certificate is fulfilled by the physician concerning health data and sent to the local administration. The certificates of Brussels inhabitants are sent and treated by the Brussels Health and Social Observatory that performs codification and quality control. Death causes were coded according to ICD-10.

Morbidity data linked to a precise diagnosis are rarely collected into a database with the exception of registries for some specific diseases such as cancer, diabetes, and tuberculosis. Those data can be approached via a surveillance network of sentinel general practitioners for some diseases (influenza) or via hospitalisation data. Another source of morbidity data lies in the “National Health Interview Survey” performed for specific years. This survey tends to be performed at European level.

Hospital admissions data concern both public and private hospitals; they were extracted from the information systems health programs (RCM: Résumé Clinique Minimum) by the Federal Ministry of Public Health. These data are total hospital admissions data and include both emergency and scheduled hospital admissions. Data for the years 2004 to 2006 were provided by hospitals and coded according to ICD-09. A conversion of the data was performed from ICD-09 into ICD-10 based on the following documents (ANDERSON, R. N., A. M. MINIÑO, D. L. HOYERT and H. M. ROSENBERG (2001). Comparability of Cause of Death Between ICD–9 and ICD–10: Preliminary Estimates, National Vital Statistics Reports, 49 (2): 1-32; EUROSTAT: «Liste européenne succincte» - G. Pavillon

(INSERM, France); CBS: Centraal Bureau voor de Statistiek, Nederland: BELDO-list; VG: Vlaams Agentschap Zorg en Gezondheid - Contact person: Heidi Cloots).

Health data are described on Table 6. The annual mean number of deaths in the general population was 8816 per year (annual rate 870 per 100.000), among which 8706 are older than 30 and among those 3150 concern cardiovascular mortality (annual rate 512 per 100.000). Those numbers exclude violent deaths such as injuries, suicides, homicides or accidents.

The annual rate of respiratory hospital admissions in the general population was 955 per 100,000 (annual number of 9675 averaged for 2004-2006). It divides between 2649 hospitalisation of individuals from 15 to 64 and 3766 for individuals of 65 and older. The annual rate is higher for the oldest.

Health outcome	**ICD9**	**ICD10**	**Age**	**Annual mean number**	**Annual rate per 100 000**
Non-external mortality*	< 800	A00-R99	All	8816	870
Non-external mortality	< 800	A00-R99	> 30	8706	1414
Cardiovascular mortality	390-429	I00-I52	> 30	3150	512
Cardiac hospitalizations	390-429	I00-I52	All	6540	646
Respiratory hospitalizations	460-519	J00-J99	All	9675	955
Respiratory hospitalizations	460-519	J00-J99	15-64 yrs	2649	262
Respiratory hospitalizations	460-519	J00-J99	≥ 65 yrs	3766	372

***Non-external mortality excludes violent deaths such as injuries, suicides, homicides, or accidents.**

Table 6 – Annual mean number and annual rate per 100 000 deaths and hospitalizations in Brussels-Capital (2004-2006)

1.4. Health impact assessment

Aphekom chose different scenarios to evaluate the health impacts of short- and long-term exposure to air pollution. The scenarios are detailed below for each air pollutant.

NOTE: Under no circumstances should HIA findings for the different air pollutants be added together because the chosen air pollutants all represent the same urban air pollution mixture and because their estimated health impacts may overlap.

The HIA method is detailed in Annex 1.

1.4.1. Short-term impacts of PM_{10}

For PM_{10}, we first considered a scenario where the annual mean of PM_{10} is decreased by 5 µg/m^3, and then a scenario where the PM_{10} annual mean is decreased to 20 µg/m^3, the WHO annual air quality guideline (WHO-AQG).

As the PM_{10} daily mean in the Brussels-Capital Region reached 26µg/m^3 during the studied period, potential benefits in decreasing the daily mean by 5µg/m^3 would reach a total of 26 postponed deaths per year whether a decrease of the daily mean to the level of 20µg/m^3 would allow to delay 31 deaths per year (Table 7 and figure 16).

Scenarios	Total annual number of deaths postponed	Annual number of deaths postponed, per 100 000
Decrease by 5 µg/m^3	26	3
Decrease to 20 µg/m^3	31	3

*** Non-external mortality excludes violent deaths such as injuries, suicides, homicides, or accidents.**

Table 7 – Potential benefits of reducing annual PM_{10} levels on total non-external* mortality in Brussels-Capital

Both scenarios have an impact on hospitalisations. Applying a 5µg/m^3 decrease of the daily mean of PM_{10} would postpone a certain number of hospitalisations, respectively 55 for respiratory problems and 20 for cardiovascular problems. A decrease of the daily mean to 20µg/m^3 would allow postponing respectively 63 and 23 hospitalisations for either respiratory or cardiovascular problems (Table 8 and figure 16).

	Respiratory hospitalisations		Cardiovascular hospitalisations	
Scenarios	**Total annual number of cases postponed**	**Annual number of cases postponed, per 100 000**	**Total annual number of cases postponed**	**Annual number of cases postponed, per 100 000**
Decrease by 5 µg/m^3	55	5	20	2
Decrease to 20 µg/m^3	63	6	23	2

Table 8 – Potential benefits of reducing annual PM_{10} levels on hospitalisations in Brussels-Capital

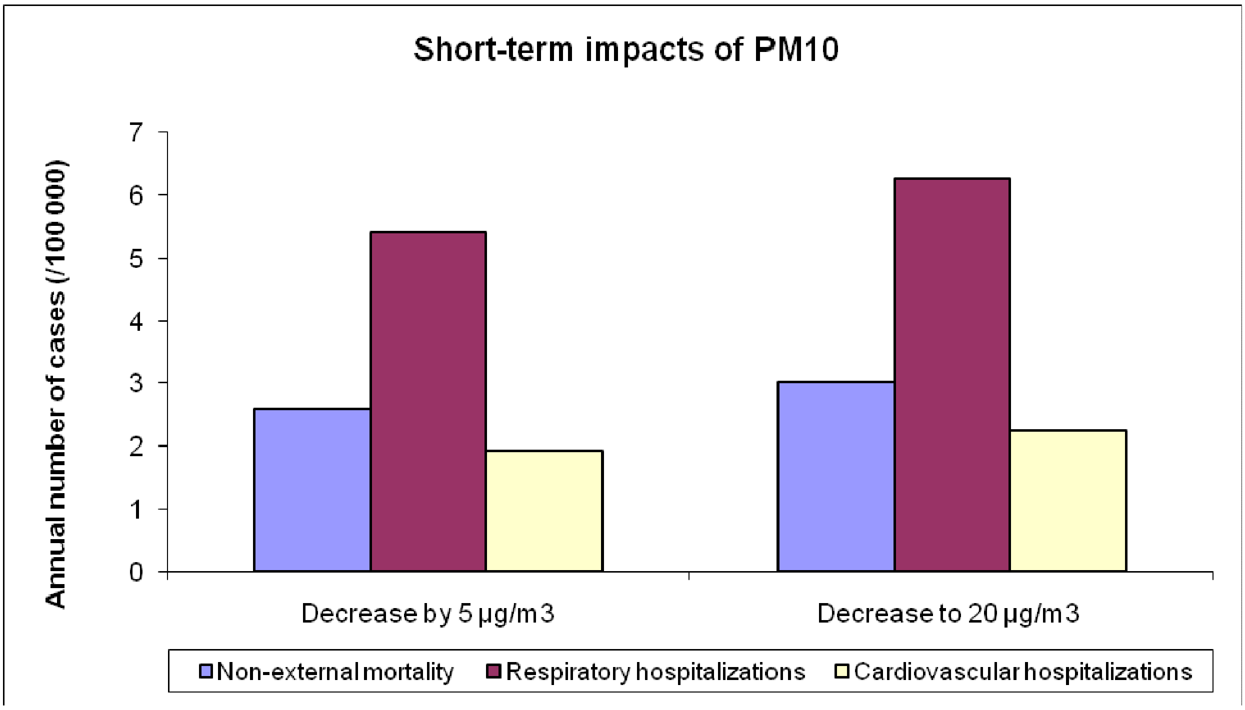


Figure 16 – Potential benefits of reducing annual PM_{10} levels on mortality and on hospitalisations in Brussels-Capital

1.4.2. Short-term impacts of ozone

For ozone, WHO set two guideline values for daily the maximum 8-hours mean concentration. The interim target value (WHO-IT1) is set at 160µg/m^3. The purpose of the interim value is to define steps in the progressive reduction of air pollution in the most polluted areas. The second value, the air quality guideline value (WHO-AQG) is set at 100µg/m^3.

We first considered a scenario where all daily values above 160µg/m^3 were reduced to WHO-IT (160µg/m^3), then a scenario where all daily values above 100µg/m^3 were reduced to WHO-AQG (100µg/m^3), and lastly a scenario where the daily mean is decreased by 5µg/m^3.

Knowing that the level of 160µg/m^3 has not been reached in the Brussels-Capital Region for the 8h maximum level of O_3, decreasing it would not have any health benefit. However the decrease of the 8h-maximum level to 100µg/m^3 would allow postponing of 8 deaths per year and furthermore, the decrease of the daily mean by 5µg/m^3 would allow postponing 14 deaths per year (Table 9 and figure 17).

Scenarios	Total annual number of deaths postponed	Annual number of deaths postponed per 100 000
8h max daily values >160 µg/m^3 = 160 µg/m^3	0	0
8h max daily values >100 µg/m^3 = 100 µg/m^3	8	1
Decrease by 5 µg/m^3	14	1

*** Non-external mortality excludes violent deaths such as injuries, suicides, homicides, or accidents.**

Table 9– Potential benefits of reducing daily ozone levels on total non-external* mortality in Brussels-Capital

On the hospitalisation side, the decrease of the 8h maximum levels of O_3 to 100µg/m^3 would allow a reduction of 1 hospitalisation for respiratory problems and 5 hospitalisations for cardiovascular causes. A further decrease by 5µg/m^3 of the daily mean of O_3 would allow reducing hospitalisations respectively by 1 for respiratory causes and by 9 for cardiovascular causes (Table 10 and figure 17). Nevertheless the small numbers, those results show the large contribution of short-term ozone exposure in cardiovascular hospitalisations.

	Respiratory hospitalizations (15-64)		Cardiovascular hospitalizations (>64)	
Scenarios	Total annual number of cases postponed	Annual number of cases postponed, per 100 000	Total annual number of cases postponed	Annual number of cases postponed, per 100 000
8h max daily values >160 µg/m^3 = 160 µg/m^3	0	0	0	0
8h max daily values >100 µg/m^3 = 100 µg/m^3	1	0	5	3
Decrease by 5 µg/m^3	1	0	9	6

Table 10 – Potential benefits of reducing daily ozone levels on hospitalizations in Brussels-Capital

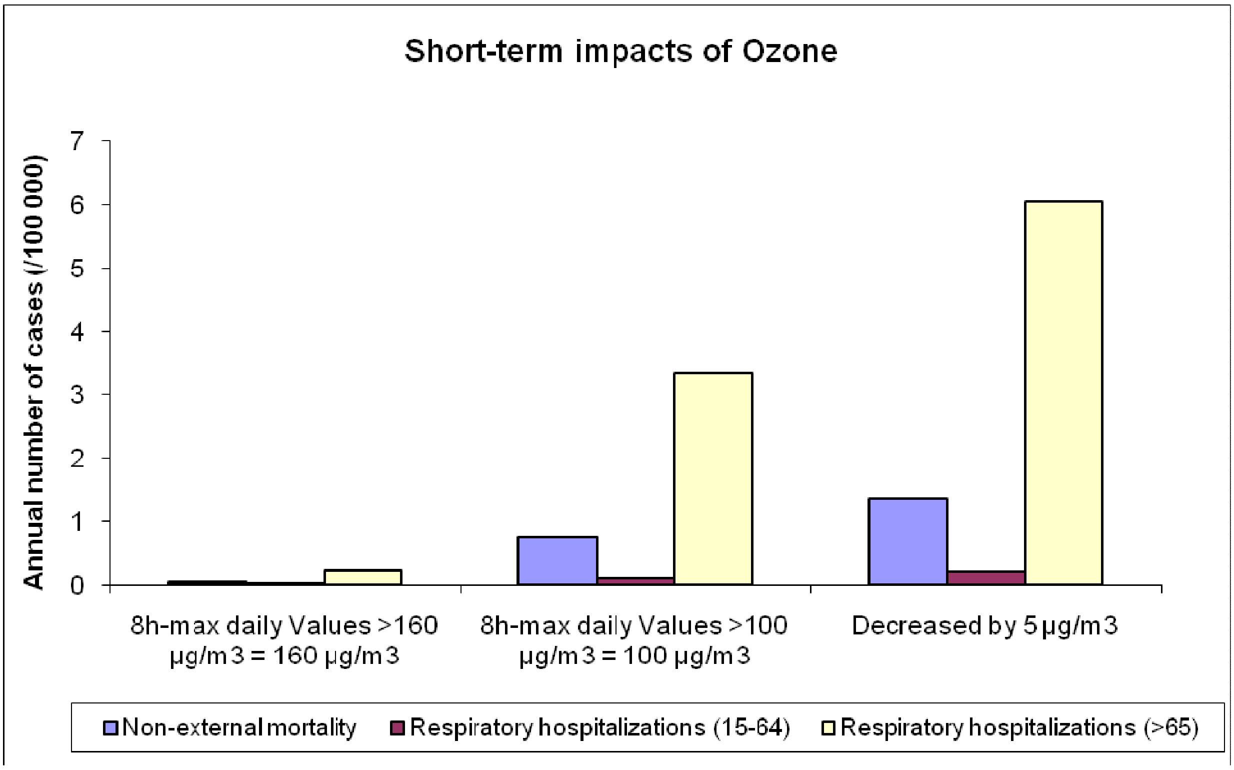


Figure 17 – Potential benefits of reducing daily ozone levels on mortality and on hospitalisations in Brussels-Capital

1.4.3. Long-term impacts of PM2.5

For PM2.5, we first considered a scenario where the PM2.5 annual mean is decreased by 5µg/m^3, and then a scenario where the PM2.5 annual mean is decreased to 10µg/m^3 (WHO AQG).

Knowing that the annual mean level of PM2.5 reaches 18µg/m^3 in the Brussels-Capital Region, a decrease by 5µg/m^3 would allow postponing of 265 deaths per year among those 174 are cardiovascular mortality (Table 11 and 12, figure 18). Furthermore a decrease to the WHO AQG (10µg/m^3) would allow the postponing of 436 deaths per year among those 283 being cardiovascular mortality (Table 11 and 12, figure 18). Long-term exposure of PM2.5 has a major impact on the cardiovascular system leading to mortality and reducing life expectancy. Although the decrease by 5µg/m^3 of the exposure to PM2.5 could lead to gain 0.3 years in life expectancy and furthermore a decrease to the level of 10µg/m^3 would lead to a gain of 0.5 year in life expectancy (Tables 11 and 12, figure 19). The second scenario accounts for a reduction of exposure being the double and potential benefits follow the same curve.

Scenarios	**Total annual number of deaths postponed**	**Annual number of deaths postponed, per 100 000**	**Gain in life expectancy**
Decrease by 5 µg/m^3	265	43	0,3
Decrease to 10 µg/m^3	436	71	0,5

Table 11 – Potential benefits of reducing annual PM2.5 levels on total mortality and on life expectancy in Brussels-Capital

Scenarios	**Total annual number of deaths postponed**	**Annual number of deaths postponed, per 100 000**
Decrease by 5 µg/m^3	174	28
Decrease to 10 µg/m^3	283	46

Table 12 – Potential benefits of reducing annual PM2.5 levels on total cardiovascular mortality in Brussels-Capital

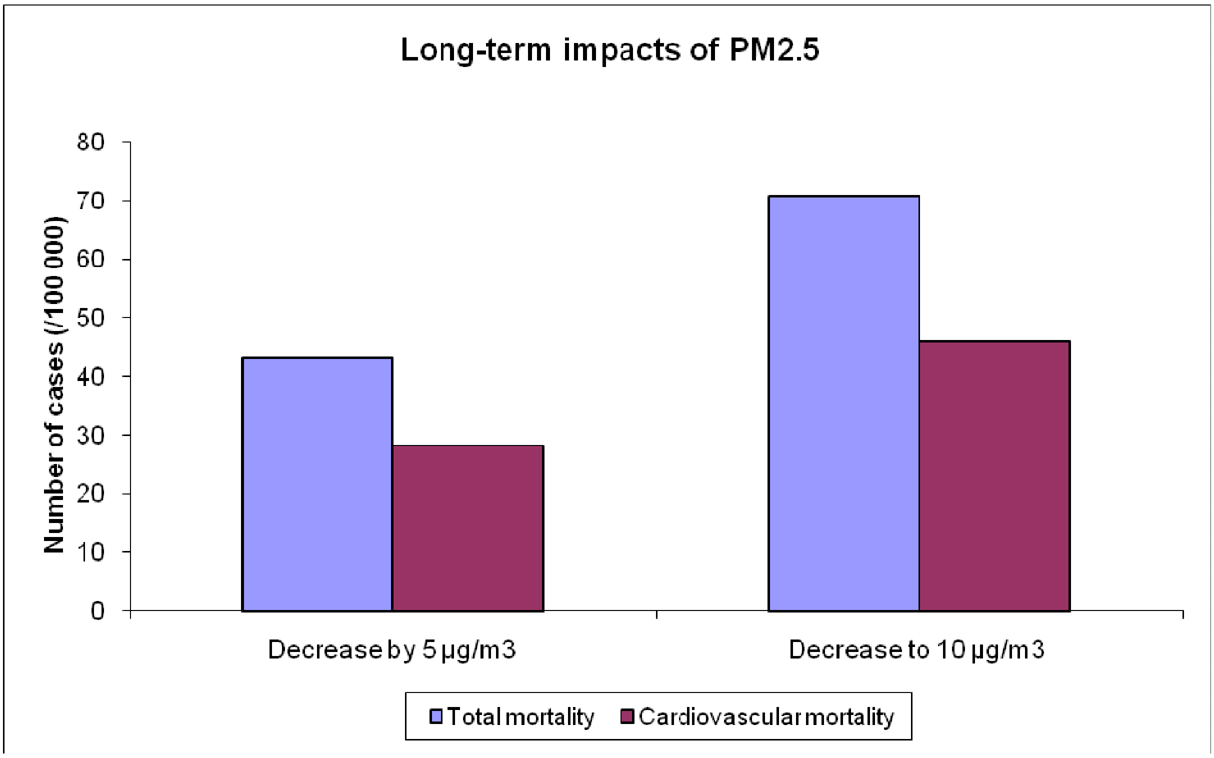


Figure 18 ─ Potential benefits of reducing annual PM2.5 levels on mortality in Brussels-Capital

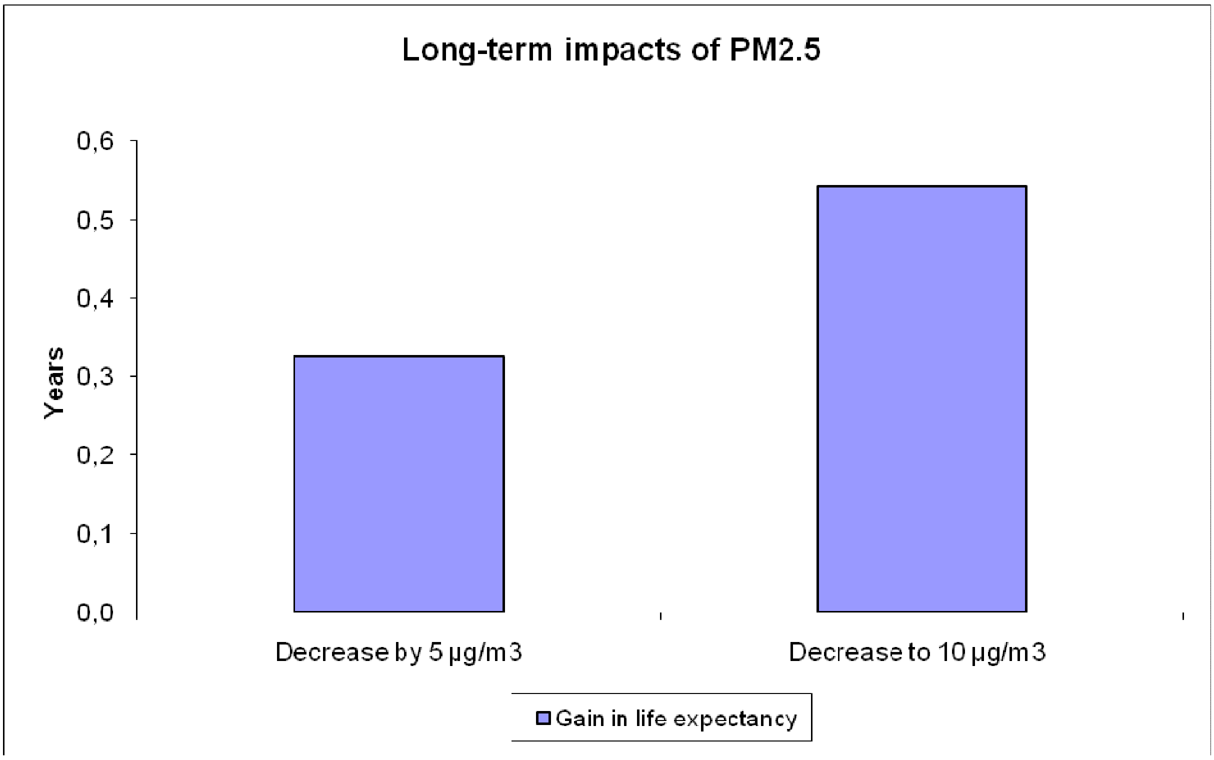


Figure 19 ─ Potential benefits of reducing annual PM2.5 levels on life expectancy in Brussels-Capital

1.4.4. Economic valuation

These HIAs provide short- and long-term potential benefits on mortality of reducing air pollution as well as the short-term potential benefits on hospitalisations.

Mortality

The monetary values chosen to assess mortality benefits are going to differ depending on the short- or long-term nature of the exposure to air pollution (see Appendix 2).

For short-term impacts, a monetary value of €86.600 per death should be applied to the total annual number of deaths postponed per city.

In Brussels-Capital Region, considering short-term impacts of the exposure to PM_{10}, a decrease of the daily mean by 5µg/m^3 would allow postponing 26 deaths per year. The annual monetary value of such benefit would reach 2.251.600€. Although a decrease of the daily mean to the level of 20µg/m^3 would allow to delay 31 deaths per year. The annual monetary value of such benefit would than reach 2.684.600€.

Considering the short-term impact of the exposure to O_3, 8 deaths per year could be postponed by reducing the 8h-maximum level of O_3 to 100µg/m^3 and 14 deaths per year could be postponed applying a decrease of the daily mean by 5µg/m^3. The annual monetary value of such benefits would respectively reach 692.800€ and 1.210.400€.

For long-term impacts, a monetary value of 1.655.000€ per death should be applied to the total annual number of deaths postponed per city.

Considering the long term impact of the exposure to PM2.5 (annual mean of 18µg/m^3) a decrease by 5µg/m^3 would allow postponing of 265 deaths and furthermore a decrease to the WHO AQG (10µg/m^3) would allow the postponing of 436 deaths per year. The annual monetary value of such benefits would respectively reach 43.8575.000€ and 721.580.000€.

The way gain in life expectancy should be estimated, is detailed in Appendix 2.

The gain in life expectancy can than be computed into a monetary valuation of 454.779.900€ when a 5µg/m^3 decrease is applied and of 757.966.500€ when a decrease to the WHO AQG is applied.

NOTE: the valuation of mortality benefits is based on stated preferences studies and will use common values for all cities together. Indeed, accounting for differences in country's GNP per capita seems ethically unacceptable to stand for the valuation of life benefits.

Hospitalisations

The standard cost of illness approach is used for short-term hospitalisations, and consists in applying unit economic values to each case, including direct and indirect costs.

The unit economic values will differ across cities, based on specific local market prices for medical resources and wages (see Appendix 2). The economic benefits related to a reduction in air pollution exposure are then computed by multiplying the number of hospitalisations in your city by the corresponding unit economic value.

The overall economic value of hospitalisations would have to be considered depending on the scenario and the targeted pollutant.

If we consider short-term exposure to PM_{10}, the monetary valuation of the reduction of the number hospitalisations would account for 365.410€ when a 5µg/m^3 decrease of the daily mean of PM_{10} is applied to the daily mean. Direct medical costs would account for 234.468€ and the corresponding indirect costs related to work loss would be of 130.928€. Nevertheless the monetary valuation of the reduction of the number of hospitalisations would account for 419.018€ when a decrease of the daily mean to 20µg/m^3 is applied.

Considering benefits of the reduction of O_3 exposure in terms of hospitalisations. The monetary valuation would account to 29.974€ when the decrease of the 8h maximum levels of O_3 to 100µg/m^3 is applied and 50.102€ when a decrease by 5µg/m^3 of the daily mean of O_3 is applied.

1.4.5. Interpretation of findings

In this report the Aphekom team have derived estimates of the health impact of both short- and long-term exposure to particles and ozone. These impacts have been estimated as the numbers of deaths and admissions attributable to air pollution avoided under different reduction scenarios. Further, these benefits have been quantified in monetary terms. Whilst there remains considerable uncertainty in the health impact assessment and in the quantification these results illustrate the magnitude of the potential benefits associated with reductions in air pollution in Brussels-Capital and more widely across Europe. It should be noted that the benefits reported are not considered to be independent of each other and are therefore not additive across pollutants. The most relevant findings are summarised in Table 13.

Scenario on short-term impact of PM_{10}	Total annual number of deaths postponed	Annual monetary benefit of the reduction of total mortality	Respiratory hospitalisations Total annual number of cases postponed	Cardiovascular hospitalisations Total annual number of cases postponed	Annual monetary benefit of the reduction of the number of hospitalisations (medical costs + work loss)
Decrease by 5µg/m^3	26	2.251.600€	55	20	365.410€
Decrease to 20µg/m^3	31	2.684.600€	63	23	419.018€

Scenario on long-term impact of PM2,5	Total annual number of deaths postponed	Annual monetary benefit of the reduction of total mortality	Annual number of cardiovascular deaths postponed	Gain in life expectancy (year)	Monetary valuation of the gain in life expectancy
Decrease by 5µg/m^3	265	438.575.000€	174	0,3	454.779.900€
Decrease to 10µg/m^3	436	721.580.000€	283	0,5	757.966.500€

Scenario on short-term impact of O_3	Total annual number of deaths postponed	Annual monetary benefit of the reduction of total mortality	Respiratory hospitalisations (15-64) Total annual number of cases postponed	Cardiovascular hospitalisations (>64) Total annual number of cases postponed	Monetary benefit of the reduction of annual number of hospitalisation
8h-max daily values ≥ 160µg/m^3	0	0	0	0	0
8h-max daily values ≥ 100µg/m^3	8	692.800€	1	5	29.974€
Decrease by 5µg/m^3	14	1.210.400€	1	9	50.102€

Table 13 – Summary of the benefits in terms of deaths postponed, hospitalisation reduction, gain in life expectancy and their respective monetary valuation for Brussels-Capital

Health impact assessment is a tool to translate research findings into quantitative information that could be used by policy makers, public health professionals and the public.

Regarding air pollution and health impact, many toxicological, experimental and epidemiological studies are in favor of a causal relationship between air pollution and mortality and morbidity, specifically cardio respiratory; however the quantification of these effects, through quantitative risk assessment methodologies, gives an impression of certainty although complexity of interactions (through multiple determinants of health) are hard to be taken into account (Künzli N. et al. (2008) An attributable risk model for exposures assumed to cause both chronic diseases and its exacerbations, Epidemiology, 19(2), O'Connell E. and Hurley F. (2009) A review of the strengths and weaknesses of quantitative methods used in health impact assessment, Public Health 123: 306-310).

Limitations accounting for health data and air quality influence the strength of the computed HIA. To be more detailed, all provided morbidity and hospitalization data have their own limitations, which can modify the base line used to test scenarios and thus calculated benefits. In the absence of morbidity registers, morbidity data have been extracted from health surveys whose main drawbacks are well known (prevalence of *perceived* (not diagnosed) health events, collected from a representative sample with large confidence intervals). Hospitalizations data come from a data bank whose initial purpose is not epidemiological; thus, admissions diagnoses (only based on the principal reason for hospitalization) can miss some respiratory or cardiovascular admissions. Moreover, admissions through emergency services cannot be distinguished from planned admissions. Finally, diagnoses for emergencies consultations were not supplied, as not available.

Air quality data were computed from a network of monitoring stations. The coverage of the network might differ from one city to the other. The Brussels-Capital coverage is quite intense but climate and geography influence the mixing of the air masses and on the other hand exposure and air quality might differ depending on the behavior of the population. Brussels-Capital is a very 'mobile' region: some residents work outside the region and more than 300 000 people come each day to work in Brussels. The concerned exposed population is thus probably different from the official one and this could modify the results as such.

Mortality, morbidity and pollution data were not supplied for the same years. The air quality data give a picture limited in time, here for a 3 years period. It accounts for both short-term and long-term impact in the HIA. The previous evolution of air quality (better or worst) is therefore not completely taken into account in the computation.

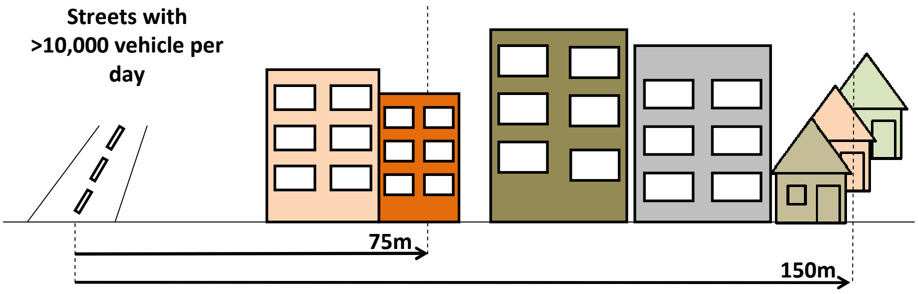
This study could be considered as a first step for policy makers. Results have to be put in a larger framework, as number of postponed death/hospitalizations and global monetary evaluation cannot be self sufficient to take decision. The institutional and political context of Brussels-Capital, the characteristics of the concerned population, the effects of other public health policies regarding morbidity and mortality, the feasibility and cost of measures aiming to reduce air pollution, and other parameters should be added in order to help decision makers to take an informed thoroughly-weighted decision.

Chapter 2. Health Impacts and Policy: Novel Approaches

Pollutants such as ultrafine particles occur in high concentrations along streets and roads carrying heavy traffic. And evidence is growing that living near such streets and roads may have serious health effects, particularly on the development of chronic diseases. Until now, however, HIAs have not explicitly incorporated this factor.

For this purpose, Aphekom has applied innovative HIA methods to take into account the additional long-term impact on the development of chronic diseases from living near busy roads. We also evaluated the monetary costs associated with this impact.

We first determined that, on average, over 50 percent of the population in the 10 European cities studied lives within 150 metres of roads travelled by 10,000 or more vehicles per day and could thus be exposed to substantial levels of toxic pollutants.



City	Population (Million. Hab)	PM_{10} annual average (ug/m^3)	% population within 75m (average 29%)	% population within 150m (average 52%)
Granada	0.24	34	14%	28%
Ljubljana	0.27	32	23%	47%
Bilbao	0.31	27	29%	59%
Sevilla	0.7	41	20%	38%
Valencia	0.74	46	44%	71%
Brussels	1.03	29	37%	64%
Stockholm	1.3	17	14%	30%
Barcelona	1.53	33	56%	77%
Vienna	1.66	25	36%	62%
Rome	2.81	37	22%	43%

Figure 20 – Estimated percentage of people leaving near busy roads

In the cities studied, our HIA showed that living near these roads could be responsible for some 15-30 percent of all new cases of: asthma in children; and of COPD (chronic obstructive pulmonary disease) and CHD (coronary heart disease) in adults 65 years of age and older.

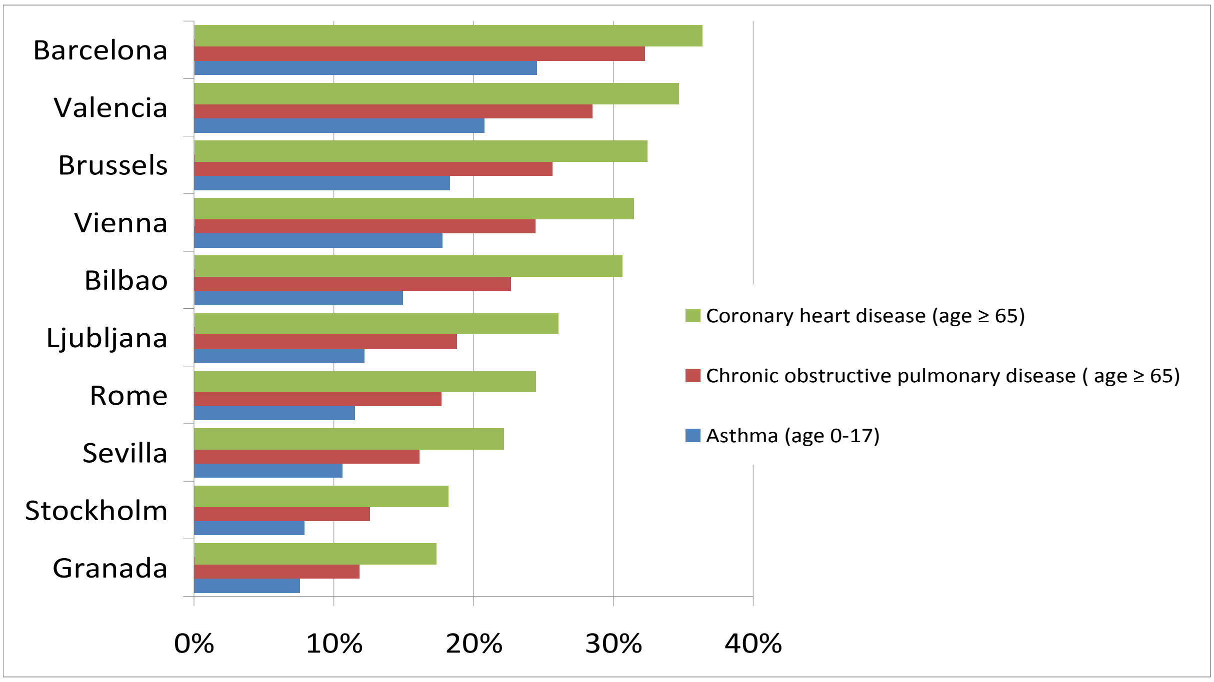


Figure 21 ─ Percentage of population with chronic diseases whose disease is attributable to living near busy streets and roads in 10 Aphekom cities

Aphekom further estimated that, on average for all 10 cities studied, 15-30 percent of exacerbations of asthma in children, acute worsening of COPD and acute CHD problems in adults are attributable to air pollution. This burden is substantially larger than previous estimates of exacerbations of chronic diseases, since it has been ignored so far that air pollution may cause the underlying chronic disease as well.

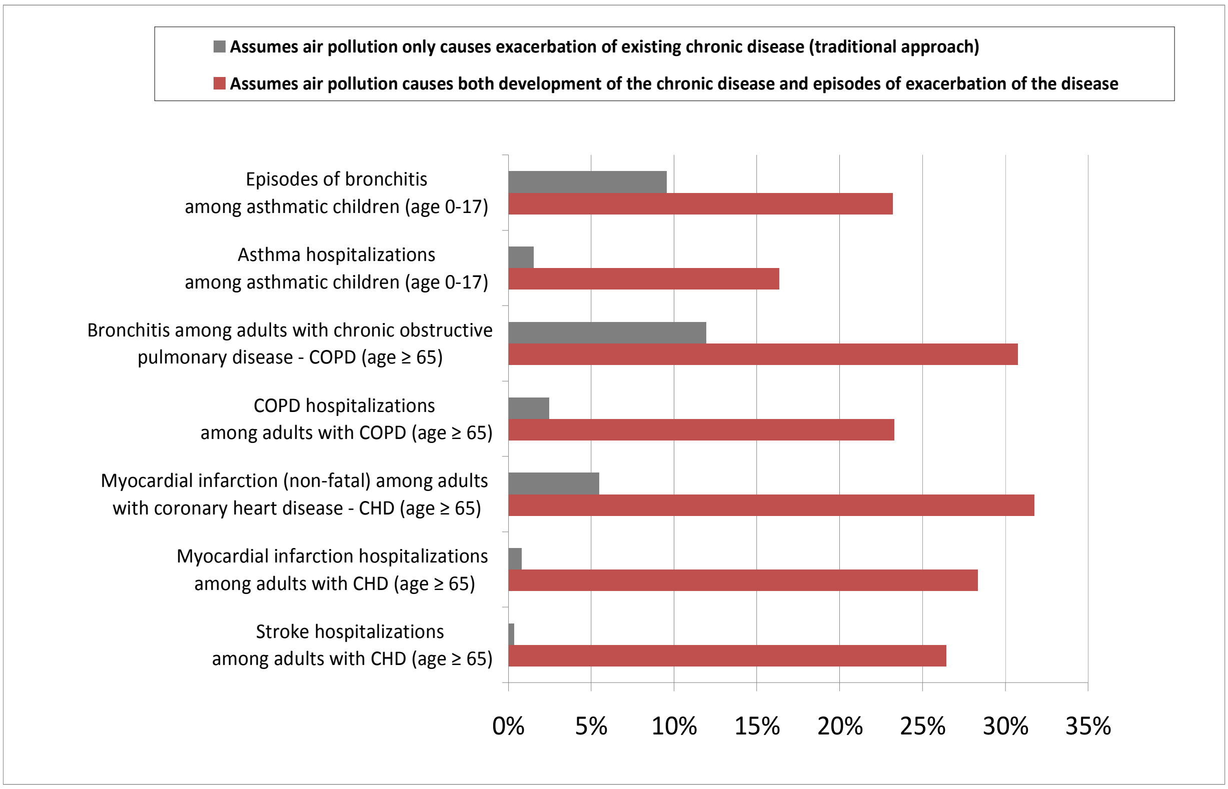


Figure 22 ─ Comparison of impact of air pollution on chronic diseases calculated using two different HIA approaches in Aphekom

In addition, for the population studied Aphekom estimated an economic burden of more than €300 million every year attributable to chronic diseases caused by living near heavy traffic. This burden is to be added to some €10 million attributable to exacerbations of these diseases.

The economic valuation is not sufficiently robust at the city level from a HIA as well as an economic perspective to allow for local computations.

Chapter 3. Health Impacts of Implemented Policies in Air Pollution

Beyond reviewing the documented benefits to health of the historic Dublin coal ban in 1990 and the recent implementation of congestion charges in London and Stockholm, Aphekom investigated the effects of EU legislation to reduce the sulphur content of fuels (mainly diesel oil used by diesel vehicles, shipping and home heating). As part of the work of the Aphekom WP6 an extensive review of the scientific literature on interventions, both legislative and coincidental which have resulted in reductions in air pollution, was conducted.

This review shows that air pollution interventions have been successful at reducing air pollution levels. It has also shown that there is consistent (significant) published evidence that most of these interventions have been associated with health benefits, mostly by way of reduced cardiovascular or respiratory mortality and or morbidity. Throughout the majority of reviewed interventions the found decrease in mortality exceeded by far the expected predicted figures based on observations European multicity studies. This provides an informed scientific basis for decision and policy makers.

In addition to that, Aphekom WP6 investigated the effects of EU legislation to reduce the sulphur content of fuels (mainly diesel oil used by diesel vehicles, shipping and home heating). In detail the effect on air pollution levels of the implementation of the Council Directive 93/12/EEC and its amended version Council Directive 1999/32/EC including marine oils were analysed. The implementation of the two Council Directives encompassed three stages of implementation gradually reducing the sulphur content in certain fuels in the EU member states with stage (I) being implemented as laid down in the directive on 1st Oct. 1994, stage (II) on 1st Oct. 1996 and stage (III) on 1st July 2000.

	Dates	Sulphur content should not exceed (by weight)	
Stage I	1st October 1994	< 0,2 % by weight	Gas oil and diesel fuels
Stage II	1st October 1996	< 0,05 % by weight	Gas oil and diesel fuels
Stage III	1st July 2000	< 0,20 % by mass	Gas oil including marine gas oil

Table 14 – implementation steps of the Council Directives 93/12/EEC and 1999/32/EC

Our analysis in 20 cities showed not only a marked, sustained reduction in ambient SO_2 levels, but also saved 2212 lives from all-cause mortality, 153 lives from respiratory-cause and 1312 lives from cardiovascular-cause mortality per year attributable to reduced ambient SO_2 for 20 European cities, spread all across Europe, from the year 2000 onwards compared to the baseline period with no directive being implemented. The resulting prevention of some 2,200 premature deaths valued at €192 million.

Air quality analysis

The general decreasing trend in daily urban background SO_2 concentrations that have been observed across all centres (except French centres excluding Paris) over the time period of the study is illustrated in Figure 23. Overall there was no clear step change in SO_2 concentrations after the implementation of the Directives, rather a gradual decline in SO_2 levels was observed.

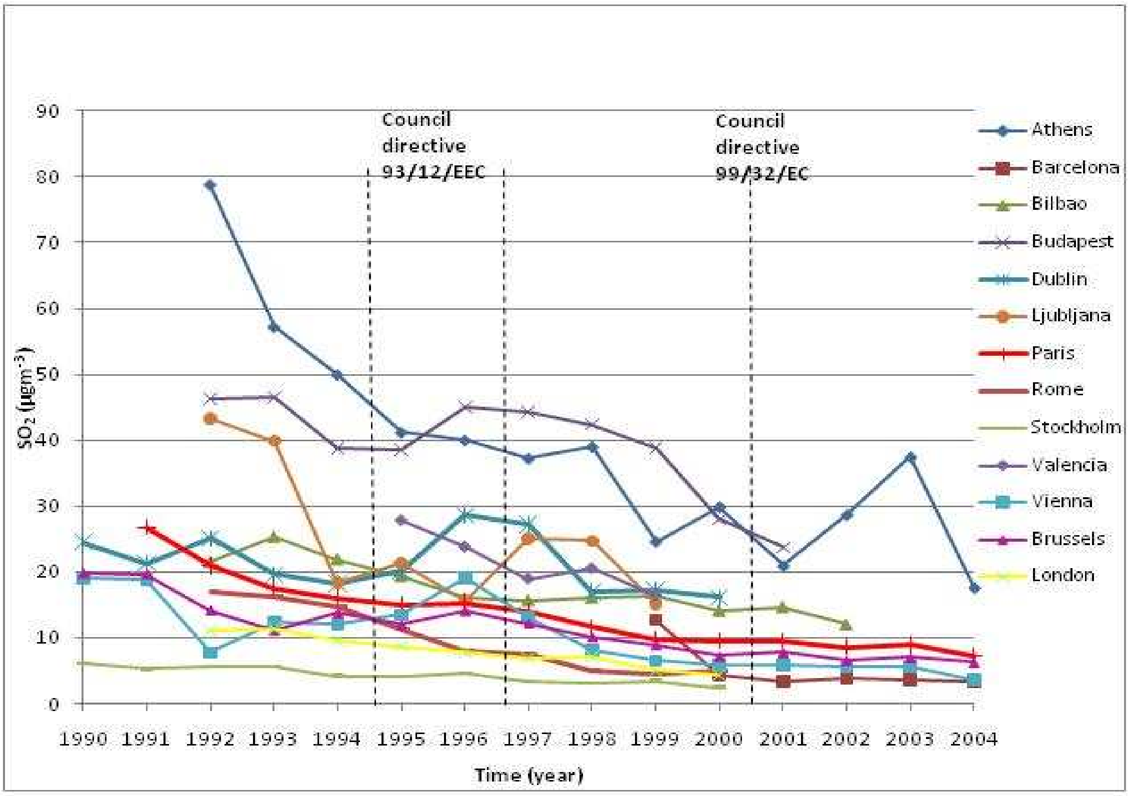


Figure 23 – Yearly urban background SO_2 averages for 13 Aphekom cities from 1990 to 2004

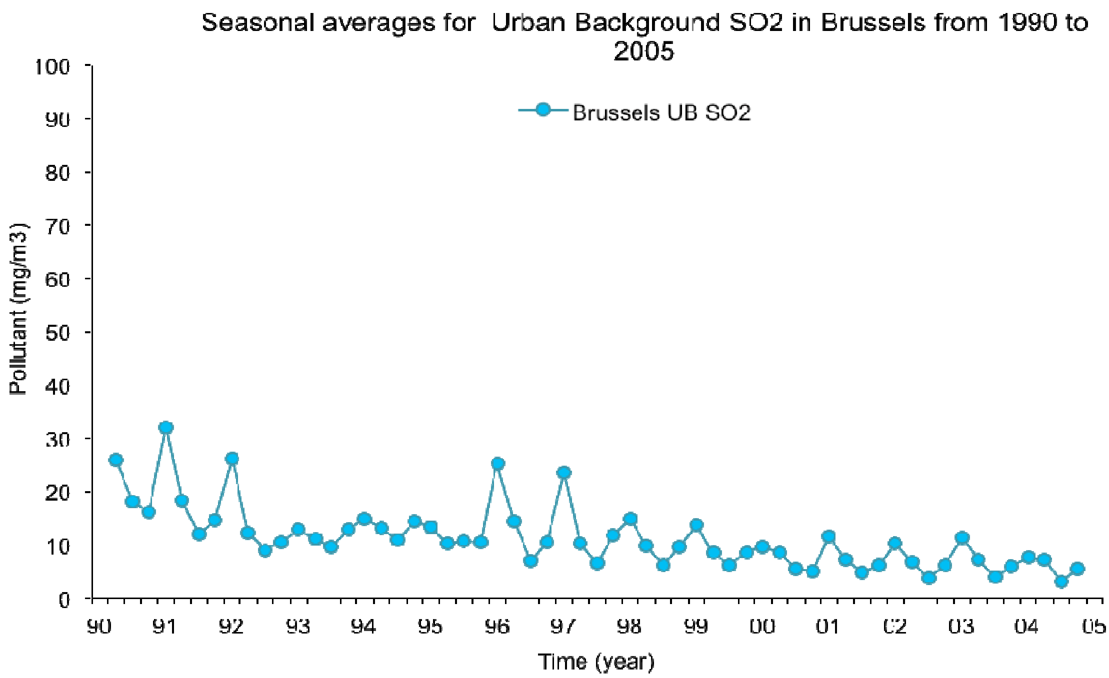


Figure 24 – Seasonal averages for urban background SO_2 in Brussels-Capital from 1990 to 2005

A rather abnormal peak of very high urban background SO_2 levels was observed simultaneously in a number of centres in the winters of 1995/6 and 1996/7. This does not mean that there are no outlying peaks now and then during the studied period in SO_2 levels for individual centres. The fact that those peaks were observed in many centres simultaneously and that individual levels were quite high compared to years before and after the observed peaks caught the attention of the WP6 team.

Furthermore, Brussels-Capital observations of the decreasing urban background of SO_2 levels are presented on Figure 24, showing seasonal averages of urban background of SO2. The detailed evolution of SO_2 in Brussels-Capital shows a regular decrease with still short peaks. Brussels-Capital observed a peak in January 1996 and another peak in January 1997. Both peaks were linked to very cold weather.

Based on the feedback received from the individual centres the most likely reason for the observed peaks happening simultaneously in a number of cities was cold wave in the winter months with peaking SO_2 levels. This coincided with observation made for a number of cities analysing daily averaged temperature data that showed prolonged periods with peaks in minimum temperatures reached in this time period. These observed cold waves went with increased fuel usage due to the increased space heating and electricity usage and as well as inversion. Another possible factor contributing to the observed SO_2 peaks could be that countries used up old stockpiles of fuel that did not comply with the directives. That might have happened independently from the cold wave or due to the fuel shortage during the prolonged cold weather.

Figure 25 and Figure 26 show preliminary work done using hourly SO_2 data from Vienna, Austria showing seasonal plots for winter (Fig. 25) and summer (Fig. 26) for a central urban station for the years 1990 to 2000. For example: In Figure 25, SO_2 levels are showing a general decreasing trend over time. The two peaks observed consistently throughout all years between 6am and noon and as well between 4pm and 11pm for the winter plots (Fig. 25) suggest that those peaks are mainly caused by traffic due to the morning and evening rush hours and as well due to space heating especially in the evenings. Comparing the two seasons the summer plot (Fig. 26) shows a clear reduction in peak SO_2 levels for therefore mentioned time periods. This might indicate the proportion of SO_2 that resulted from emissions due to heating during the winter months especially as high SO_2 levels are observed for a few consecutive hours from ~5pm up to midnight coinciding with inversion. The smaller peaks are still observed again coinciding with the morning and evening rush hours and also reflecting climatic effects. *To be computed for Brussels-Capital*

In Fig. 25 the observed winter SO_2 levels for the central urban station in Vienna in 1990 are markedly higher than later years and even though if the peak patterns look like in the other years the observed high SO_2 levels do not necessarily have to be caused by traffic! It is not clear, if these high SO_2 values were reached due to high sulphur content in diesel fuel for vehicles or due to other sources, such as fuel oil combustion, heating, being emitted simultaneously with the traffic related emissions.

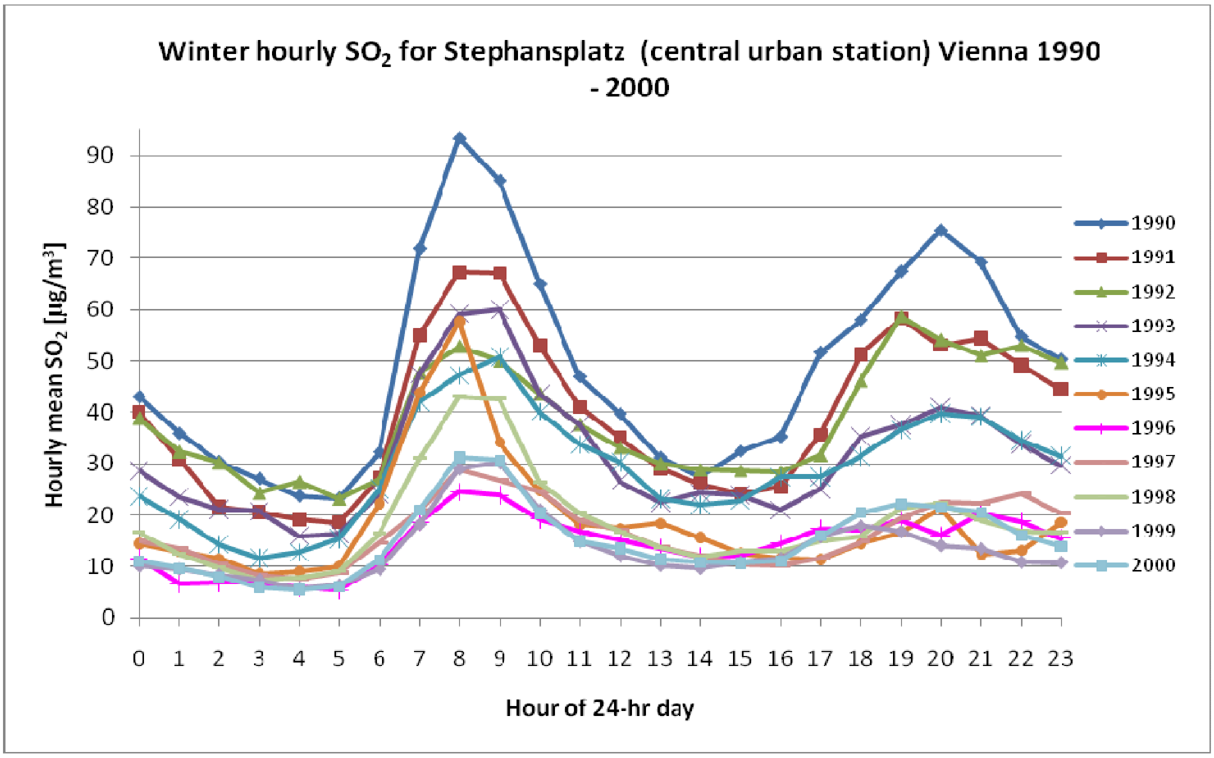


Figure 25 – Diurnal plot of winter hourly SO_2 for a central urban station in Vienna 1990-2000

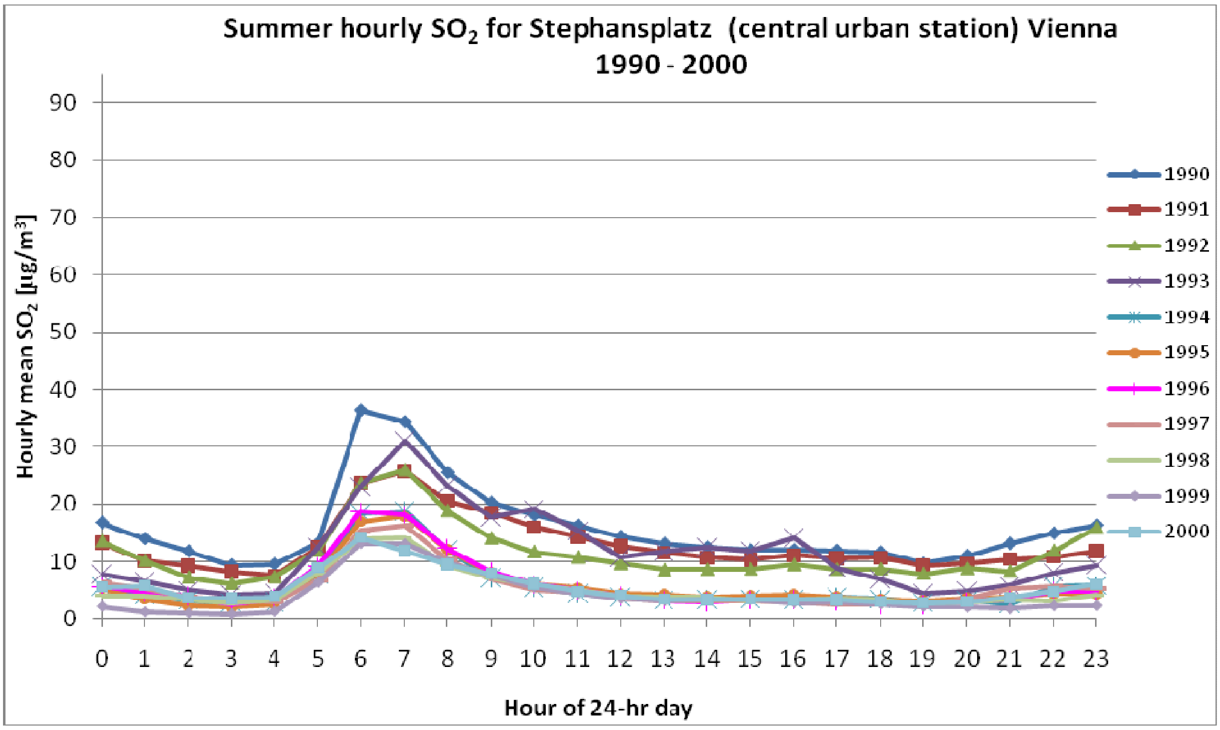


Figure 26 – Diurnal plot of summer hourly SO_2 for a central urban station in Vienna 1990-2000

Figure 27 shows a 24hr-plot of hourly SO_2 data from an urban background station in London averaged for the winter months. In comparison to the pattern observed in Fig. 25 for Vienna, where 2 distinct peaks throughout the day for the winter months were observed, here in Fig.25 levels tend to rise markedly in the morning hours and then entering a plateau period with minor variations during day time and declining from 6pm in the evening in 1992 to 1998. One possible explanation for these elevated SO_2 levels during midday might be that it reflects the metropolitan life-style of the city involving constant traffic use. This constant traffic might have been picked up by the urban background measuring station as London Bloomsbury is very central in the city centre. *To be computed for Brussels-Capital.*

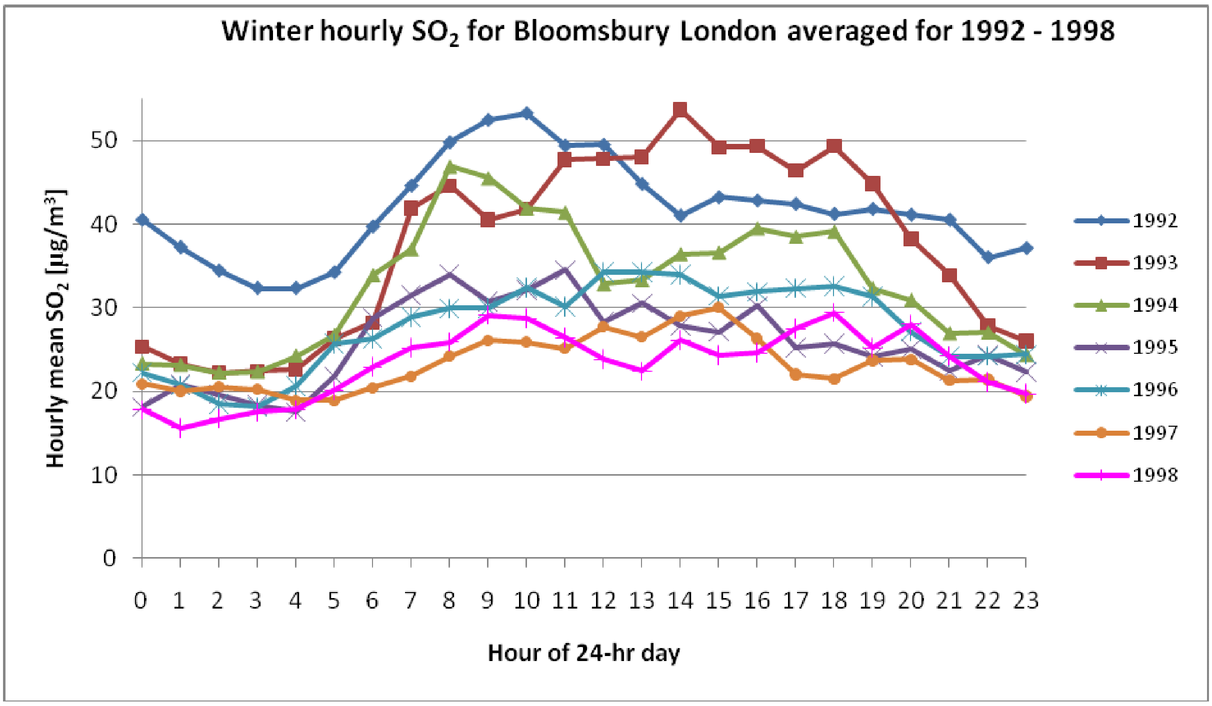


Figure 27 – Diurnal plot of winter hourly SO_2 for an urban background station in London 1992-1998

Time-series analysis

It has to be noted that not all countries with collaborating cities have complied with the implementation dates laid down in the Council Directives due to various reasons, e.g. local derogations sought etc., and thus the implementation dates and the number of stages implemented are not all the same. Therefore the 14 centres including Athens, Bordeaux, Brussels, Dublin, Le Havre, Lille, London, Lyon, Marseille, Paris, Rome, Rouen, Stockholm and Strasbourg that implemented all three stages of the Council Directives were analysed separately.

The health data analysis showed no evidence of change of slope in the dose-response curve after implementation of the legislations and hence observed effects were related to level changes.

The implementation of the first stage in 1994 reduced annual deaths by 639 deaths from all causes, by 47 deaths from respiratory and by 361 deaths from cardiovascular causes compared to the baseline period prior to October 1994 with no directive being implemented.

The implementation of the 2nd stage in 1996 reduced annual deaths by 1093 deaths from all causes, by 83 deaths from respiratory and by 610 deaths from cardiovascular causes compared to the baseline period with no directive being implemented.

The implementation of the 3rd stage in 2000 reduced annual deaths by 1616 deaths from all causes, by 127 deaths from respiratory and by 889 deaths from cardiovascular causes compared to the baseline period with no directive being implemented.

On a city specific level, for Brussels-Capital:

The implementation of the first stage in 1994 reduced annual deaths by 14 deaths from all causes, by 1 death from respiratory and by 7 deaths from cardiovascular causes compared to the baseline period prior to October 1994 with no directive being implemented.

The implementation of the 2nd stage in 1996 reduced annual deaths by 30 deaths from all causes, by 2 death from respiratory and by 14 deaths from cardiovascular causes compared to the baseline period with no directive being implemented.

The implementation of the 3rd stage in 2000 reduced annual deaths by 54 deaths from all causes, by 4 deaths from respiratory and by 26 deaths from cardiovascular causes compared to the baseline period with no directive being implemented.

As a result on a city specific level for Brussels-Capital (summarized in Table 15) and overall for the 14 cities that implemented all 3 stages of the fuel legislation it was found that the efficiency/effectiveness/impact of the legislation based on lives saved, if we didn't apply any regulation, increased throughout the different stages of implementation overtime with more lives being saved after implementation of the 2nd stage of implementation compared to the first stage and with more lives being saved after implementation of the 3rd stage of implementation compared to the 2nd one.

Time period	All cause mortality			Respiratory mortality			Cardiovascular Mortality		
	cases per year	95 CI -	95 CI +	cases per year	95 CI -	95 CI +	cases per year	95 CI -	95 CI +
Stage 1 [≥ 01.10.1994 and <01.10.1996]	14	5	23	1	0	2	7	2	11
Stage 2 [≥ 01.10.1996 and <01.07.2000]	30	10	49	2	-1	5	14	4	24
Stage 3 [≥ 01.07.2000]	54	19	90	4	-1	9	26	8	44

Table 15 -- Summary of lives saved per implementation stage (1-3)/intervention (and 95% Confidence Intervals) per year in Brussels-Capital for different mortality groups compared the baseline period (<01.10.1994) with no legislation implemented

Valuation of the benefits of EU legislation to reduce the sulphur content of fuels

The local estimates are not sufficiently robust at the city level to allow a local HIA so it has been decided to use the meta-results for the local economic valuation.

The legislation has two potential effects on mortality: short-term and long-term. It has been decided that, to take a conservative standpoint, mortality effects will be considered as short-term effects.

The value of a life year (VOLY) was estimated to be €86,600. Our analysis in 20 cities showed not only a marked, sustained reduction in ambient SO_2 levels but also the resulting prevention of some 2,200 premature deaths valued at €192 million. The economic evaluation thus constitutes a lower bound of the mortality benefits of the legislation.

Chapter 4. Sharing Knowledge and Uncertainties with Stakeholders

Uncertainties perceived by scientists, policy makers and other stakeholders could undermine their confidence in the findings of HIAs. For this reason, Aphekom has developed a method that helps them discuss and share their views on both the uncertainties in HIA calculations and their impact on the decision-making process.

In addition, to help decision makers draft policies on air quality and related environmental-health issues, Aphekom has developed a process, based on a deliberation-support tool, that helps frame and structure exchanges between stakeholders working together. Using this process enables them to propose and discuss multiple criteria for evaluating, prioritising and aligning their various needs, and for choosing actions that match their objectives and preferences.

Brussels-Capital: case study for the test of a multidisciplinary deliberation-support tool

Brussels-Capital as a Region is currently implementing a “Structural action plan to improve air quality and mitigate climate change” for the period 2002-2010. This period coming to an end, the preparation of a new action plan has been set on the agenda for 2010. The Region has also the obligation to transpose European Directives into its legislative toolbox. Therefore, the scope of the new action plan had been enlarged in order to integrate the topics of air quality, energy and climate.

The issue to be addressed was the opportunity to involve several different departments of the Brussels Administration for the Environment for the preparation of the new integrate action plan, and to do so as early as during the drafting phase. In doing so, integration of the different topics was ensured, empowerment of departments would support and enhance their degree of preparedness for later negotiations with decision-makers (attachés of the ministerial cabinet) and eventually develop a common position with the objective of integrating health as a federative aim to the action plan.

The Regional Administration for the Environment (Brussels Institute for the Management of the Environment) has the responsibility of the preparation of the new action plan under the competency of the minister for environment, water and energy.

The preparation of action plans is based on a multidisciplinary approach involving the various departments concerned with the thematic. In the case of the integrate action plan on air, climate and energy, the department « integrated planning air, energy and climate » would coordinate the work with the support of a working group. The later would require the participation of the departments dealing with data analysis, monitoring of air quality, health and environment, energy, transport interface and urban planning, authorisation, inspection, communication and information. It involves also departments dealing with connected thematic such as noise, waste, buildings, water and green spaces.

The working group had been meeting for several months yet. It reached a draft version of the action plan, amended to a near-finished version by the working group participants. The issue was to prepare the coming negotiation with the attachés of the ministerial cabinet and to keep proactive objectives in order to improve Brussels air quality. It was decided to improve the draft version of the integrate action plan with a multidisciplinary tool to support decision.

It was decided to choose 3 actions among the near-ready actions and to have those worked out with the deliberation matrix by the working group participants and invite 2 members of the Brussels Observatory for Health and Social as observers. The 3 chosen actions were related to a wider range of topics than air, energy and climate.

The measures to be assessed were chosen by members of the IBGE.

- **Agro fuels**: Chapter on transport, measure n°2: support the im provement of the environmental performance of vehicles; measure n°8: manage the delivery of goods for the population of Brussels. The text specifies, “Encourage the use of less polluting vehicles and alternative sources of energy such as agro fuels”.
- **Types of vehicles**: Chapter on transport, measure n°2: support the im provement of the environmental performance of vehicles; measure n°8: manage the delivery of goods for the population of Brussels. The text specifies, “Encourage public bodies to buy less polluting vehicles”.
- **Low emission zones**: Chapter on transport, measure n°4: re-examine the road capacities in the light of environmental objectives and define low emission zones. The text specifies, “Define low emission zones, zone 30 and both cycling and pedestrian roads”.

Results of the use of the deliberation-support matrix

A first task was to amend, complete and validate the performance issue table (basis of the assessment). There was a consensus on the necessity to add a category of institutional issues. Therefore, a complete table was elaborated (Table 16).

Three sub categories were created:

- Incomplete or overlapping responsibilities
- Strategies and political priorities,
- Implementation success (chance of),

Determinants were given for each sub category to make them more accessible.

Performance issue	sub-categories	Options		
		Agrofuels	Types of vehicles	Low emission zones
Equity and social aspects	Vulnerable or deprived sub groups			
	Equitable access to measures and services			
	Environmental justice			
	Distant consequences			
Economic development	Creation of wealth			
	Job opportunities			
	Economic attractivity			
Health and quality of life	Impacts on living environments			
	Attractivity of the living environment			
	Individual aspects			
Equilibrium of the environment	Direct impacts			
	Indirect impacts			
Institutional aspects	Incomplete responsibility			
	Current strategies and political priorities			
	Implementation success			

Table 16 – Performance issue table modified by the working group in Brussels-Capital

The rest of the tables were reviewed (one for each category of performance issues), so that each participant can provide input. The goal was to cover each category as completely as possible and provide determinants to achieve a shared view of the problem.

There were important additions:

- Socially or economically un-favoured populations were included in the vulnerable groups.
- Access to knowledge was added to the sub-category “Equitable access to measures and services”.
- A new sub-category was deemed necessary: Distant consequences, with “Change of agricultural production modes” and “Impacts on land-use and price” as determinants.
- The attractiveness of the living environments was identified as a sub-category in the table on Health and Quality of life, with the addition of a determinant: housing typology.
- The determinant “Freedom to chose” was added to the sub-category “Individual aspects”.

The table on environmental impacts was modified with a new direct impact: “Limitation of emitting activities”. Two indirect determinants were also added: limitation of trans boundary pollution and Insecurity of energy supply.

Each participant then proceeded to fill the assessment table according to the colour grades (see Table 17) and the results show on Table 18.

Choices refer to the participant's anticipation of the effects of a policy measure that would be implemented									
Satisfactory		Limited		Ambiguous		Negative		No response	

Table 17 – colour code to fulfil the assessment table by each participant

Performance issue	sub-categories	Options																				
		Agrofuels							Types of vehicles							Low emission zones						
Equity and social aspects	Vulnerable or deprived sub groups	0	0	0	-1	0	0	0	0	1	0	1	-1	0	2	0	2	2	-1	-1	-1	1
	Equitable access to measures and services	0	0	-1	1	0	1	0	-1	1	2	1	-1	0	1	-1	-1	1	0	0	1	1
	Environmental justice	0	0	0	1	0	1	0	0	1	1	0	0	0	2	0	-1	2	NR	-1	1	1
	Distant consequences	-1	-1	-1	-1	-1	-1	-1	1	1	0	1	0	0	1	2	-1	0	NR	0	0	0
Economic development	Creation of wealth	1	0	1	1	1	2	1	1	2	0	1	2	0	2	1	2	0	1	0	1	1
	Job opportunities	1	1	1	1	1	2	1	1	2	0	1	2	1	2	1	2	0	0	0	1	1
	Economic attractivity	0	0	0	0	1	0	0	1	1	1	1	0	0	2	2	2	2	1	2	1	1
Health and quality of life	Impacts on living environments	0	0	-1	-1	-1	0	0	1	1	0	1	1	2	2	2	2	1	1	2	2	1
	Attractivity of the living environment	0	0	0	-1	0	0	0	1	2	2	0	1	1	2	2	2	2	1	2	2	1
	Individual aspects	0	-1	0	0	0	0	1	1	0	0	1	0	1	1	2	2	2	-1	2	2	2
Equilibrium of the environment	Direct impacts	0	-1	-1	0	0	1	0	1	0	2	1	0	1	2	2	1	1	1	2	2	2
	Indirect impacts	-1	-1	0	-1	-1	0	1	1	1	2	0	1	1	2	1	1	1	0	0	1	1
Institutional aspects	Incomplete responsibility	1	-1	1	-1	-1	-1	1	1	0	-1	0	-1	-1	1	2	2	2	0	0	2	1
	Current strategies and political priorities	2	-1	1	-1	-1	1	1	2	0	0	0	0	1	1	2	-1	1	0	-1	1	1
	Implementation success	2	NR	2	0	-1	1	1	2	0	NR	0	-1	1	1	2	2	2	NR	0	2	1

Table 18 – Results of assessment table filled by Brussels-Capital participants

The balance is clearly on the negative side for the Agro fuels measure (dominant of red and orange votes). It seems more positive for the Low emission zones and is clearly ambivalent for the vehicle technology. Among the participants, there is a relative homogeneity of judgements on the Agro fuels, with the exception of the institutional sub categories.

There is a disparity on the votes about vulnerable sub-populations. A discussion should help clarify if this is due to an ambiguity in the framing (formulation of the question, determinants), or if it represents true dissent among participants. Differences in understanding of terminology or even good knowledge of the institutional framework may explain part of the dispersion, despite the preparatory work on sub-categories and determinants.

These results provided the basis for this on line forum, which allows the initial participants to comment each other votes and, hopefully converge for some of the points.

At first, the results led to an increase of the awareness level of each participant towards other aspects of the issue.

Than later on, as the text underwent negotiations, the text evolved towards a common document and it changed the 3 prescriptions on which the exercise was done. The 3 prescriptions were totally rewritten to integrate results form the use of the process and the tool. As we look at the latest draft dated January 2011, the 3 prescriptions have evolved:

- Types of vehicles: Objectives were reinforced to decrease emissions and integrate health in the tool used to choose vehicles. The prescription is made mandatory for public bodies, in order to show the example.
- Low emission zones: The main concern raised was that such prescription could increase inequalities, and impact negatively vulnerable population, the prescription has been transformed in a pilot case study in the historic centre of the Brussels-Capital Region and an evaluation of the pilot case study before any larger implementation

- Agro fuels: The text has been modified fundamentally to accommodate a priority to low emission vehicles and the use of energy from renewable source, it does not use the wording “agro fuels” any more.

Chapter 5. Overview of findings and local recommendations

In this report the APHEKOM team have derived estimates of the health impact of both short- and long-term exposure to particles and ozone. These impacts have been estimated as the numbers of deaths and admissions attributable to air pollution avoided under different reduction scenarios. Further, these benefits have been quantified in monetary terms. Whilst there remains uncertainty in the health impact assessment and in their monetary quantification these results illustrate the magnitude of the potential benefits associated with reductions in air pollution in Brussels-Capital and more widely across Europe. It should be noted that the benefits reported are not considered to be independent of each other and are therefore not additive across pollutants.

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Marie Poupé, Department Action Plan Noise, Brussels Institute for the Management of the Environment
Véronique Verbeke, Department State of the Environment and Indicators, Brussels Institute for the Management of the Environment
Annick Meurrens, Division Research, Indicators and Health, Brussels Institute for the Management of the Environment
Jean Legrand, Federal Services for Health, Food Safety and Environment
Katia Aksajef, Anne Henau, Brussels Institute for Statistics and Analysis
Koen Vanderkerkhove, Thierry Duquenne, Mobility Brussels – Brussels Administration for Infrastructures and Transport

Appendix 1 – Health impact assessment

For each specific relationship between health outcomes and pollutants, the health impact function was

$$\Delta y = y_0(1 - e^{-\beta\Delta x})$$

where Δy is the outcome of the HIA
y_0 is the baseline health data
Δx is the decrease of the concentration defined by the scenario
β is the coefficient of the concentration response function (β=log(RR per 10 µg/m^3)/10)

The impact of a decrease of the pollutant concentration on the life expectancy was computed using standard abridged (5-year age groups) life table methodology, using the mortality data for each age group. We applied a reduction factor to the mortality rate, noted ${}_nD_x$, according to

$${}_nD_x^{impacted} = {}_nD_x * e^{-\beta\Delta x}$$

Δx is the decrease of the concentration defined by the scenario
β is the coefficient of the concentration response function.

Concentration response functions (CRFs) were selected from the literature, favouring multi-cities studies located in Europe (Table 1).

Table 1 – Health outcome and relative risks used in the HIA

HIA	Health outcome	Ages	RR per 10 µg/m^3	Ref
Short-term impacts of PM_{10}	Non-external mortality	All	1.006 [1.004-1.008]	(4)
	Respiratory hospitalizations	All	1.0114 [1.0062-1.0167]	(5)
	Cardiac hospitalizations	All	1.006 [1.003-1.009]	(5)
Short-term impacts of O_3	Non-external mortality	All	1.0031 [1.0017-1.0052]	(6)
	Respiratory hospitalizations	15-64	1.001 [0.991-1.012]	(4)
	Respiratory hospitalizations	>=65	1.005 [0.998-1.012]	(4)
Long-term impacts of PM2.5	Total mortality	>30	1.06 [1.02-1.11]	(7)
	Cardiovascular mortality	>30	1.12 [1.08-1.15]	(8)

PM_{10}

For PM_{10}, we first considered a scenario where the annual mean of PM_{10} is decreased by 5 µg/m^3, and then a scenario where the same PM_{10} annual mean is decreased to 20 µg/m^3, the WHO air quality guideline (WHO-AQG).
The exposure indicator of PM_{10} was the annual mean, calculated as the arithmetic mean of the daily concentrations of the selected stations. The corresponding Δx for the two scenarios are:

- Scenario 1, $\Delta x = 5\ \mu g/m^3$
- Scenario 2, $\Delta x = ([PM10]_{mean} – 20\ \mu g/m^3)$.
  $\Delta x = 0$ if $[PM10]_{mean} < 20$

Ozone

For ozone, WHO set two values for the daily maximum 8-hours mean. The interim target value (WHO-IT1) is set at 160 µg/m^3. The purpose of the interim value is to define steps in the progressive reduction of air pollution in the most polluted areas. The air quality guideline value (WHO-AQG) is set at 100 µg/m^3.

We first considered a scenario where all daily values above 160 µg/m^3 were reduced to WHO-IT (160 µg/m^3), then a scenario where all daily values above 100 µg/m^3 were reduced to WHO-AQG (100 µg/m^3), and lastly a scenario where the daily mean is decreased by 5 µg/m^3.

The exposure indicator of ozone was the cumulated sum over defined thresholds, calculated using 8hours-daily values.

$$\Delta x = \frac{\sum_{i=1}^{N} O_i}{N}$$

The corresponding Δx for the two scenarios are;

- Scenario 1, if $[O_3]_i \geq 160\ \mu g/m^3$, $Oi=([O_3]_i-160)$
  if $[O_3]_i < 160\ \mu g/m^3$, $Oi=0$

- Scenario 2, if $[O_3]_i \geq 100\ \mu g/m^3$, $Oi=([O_3]_i-100)$
  if $[O_3]_i < 100\ \mu g/m^3$, $Oi=0$
- Scenario 3, where the ozone yearly mean is decreased by 5 µg/m^3. $\Delta x = 5\ \mu g/m^3$

PM2.5

For PM2.5, we first considered a scenario where the PM2.5 annual mean is decreased by 5 µg/m^3, and then a scenario where the PM2.5 annual mean is decreased to 10 µg/m^3 (WHO annual AQG). The exposure indicator of PM2.5 was the yearly mean, calculated as the arithmetic mean of the daily concentrations of the selected stations. The corresponding Δx for the two scenarios are;
- Scenario 1, $\Delta x = 5\ \mu g/m^3$
- Scenario 2, $\Delta x = ([PM2.5]_{mean} – 10\ \mu g/m^3)$
  $\Delta x = 0$ if $[PM2.5]_{mean} < 10$

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Appendix 2 – Economic valuation

Because the air pollution measures as well as epidemiologic data cover the 2004-2006 period for most of the cities, all costs are consequently expressed in **euros 2005**. Similarly, the average lengths of stay in hospital required for the benefits computations are for 2005.

Valuation of mortality benefits

Regarding mortality, we follow the standard valuation procedure adopted in Cafe (2005), NexExt (2003), ExternE (2000), which consists in **using a Value of a Statistical Life (VSL) and a Value of a Life Year (VOLY) derived from stated preferences surveys**, hence relying on preference-derived values rather than market-derived values. We chose to rely on values obtained in recent European studies (see final Aphekom report for more details).

The choice of the monetary value to assess mortality benefits associated to a decrease in air pollution level depends on the type of impact.

- **For short-term mortality calculations**, the annual number of deaths postponed per year is used. Because the gains in life expectancy corresponding to each of these postponed deaths can be considered in the range of a few months, certainly lower than one year (Cafe 2005, Vol 2, p. 46), *a VOLY of €86,600 is applied to each deaths postponed to compute annual benefits.*

- **For long-term mortality calculations**, the magnitude of the gain in life expectancy related to the deaths postponed is considered as higher than a year (see Ezzati et al., 2002; Hurley et al. 2005; Watkiss et al. 2005; or Janke et al., 2009). A *VSL of €1,655,000 is applied to each deaths postponed to compute annual benefits.*

- **For long-term life expectancy calculations**, an average gain in life expectancy for persons 30 years of age is also computed using life tables and following a cohort until complete extinction. *The annual corresponding benefits are obtained by multiplying the average gain in life expectancy by the number of 30-year-old individuals in the city, and by the VOLY.* This corresponds to the benefits (in terms of life expectancy) 30 year-old people would gain over their lifetime if exposed to the 10 µg/m^3 average annual level of PM2.5 (WHO's Air Quality Guideline) instead of the current existing air pollution level in the city.

Valuation of hospitalisations benefits

The standard cost of illness approach is used for acute hospitalisations, and consists in applying unit economic values approach to each case, including direct medical and indirect costs.

The direct medical costs related to cardiac and respiratory hospitalisations are computed as the cost per inpatient day times the average length of stay in hospital. These cost data are taken from CEC (2008) for all twelve countries where the cities analysed in Aphekom are located (see Table 1). The average lengths of stay in days are obtained from the OECD Health Database (2010) for all countries except Romania (which is imputed from the population weighted average lengths of the 11 other countries).

The indirect costs are computed as the average gross loss of production per day times twice the average length of stay in hospital. Since we cannot control whether these days were actual working days, we then compute the daily loss of production as the average gross earnings in industry and services (full employment) obtained from Eurostat (2003) for each country, expressed in 2005 and divided by 365 days.

The total medical costs for cardiac and respiratory hospitalisations are obtained by adding together the direct and indirect components.

Table 1 Average lengths of stay, daily hospitalisation costs and work loss, and total hospitalisations cost per patient.

Country	Average length of stay in days[a]		Average cost per day (€ 2005)		Total costs related to hospitalisation (€ 2005)	
	Circulatory system	**Respiratory system**	**Hosp. all causes[b]**	**Work loss[c]**	**Circulatory system**	**Respiratory system**
Austria	8.2	6.6	319	83	3,977	3,201
Belgium	9.2	8.8	351	98	5,032	4,814
France	7.1	7.1	366	83	3,777	3,777
Greece	7.0	5.0	389	48	3,395	2,425
Hungary	7.4	6.5	59	18	703	618
Ireland	10.5	6.9	349	81	5,366	3,526
Italy	7.7	8.0	379	62	3,873	4,024
Romania	8.5[d]	7.4[d]	57	6	587	511
Slovenia	8.6	7.3	240	34	2,649	2,248
Spain	8.5	7.4	321	55	3,664	3,189
Sweden	6	5.2	427	92	3,666	3,177
United Kingdom	11.4	8.0	581	116	9,268	6,504
Mean[d]	**8.5**	**7.4**	**373**	**73**	**4,411**	**3,840**

Sources: *[a] OECD Health Data (2010); [b] CEC (2008), annex 7, cost/bed/day corr; [c] Eurostat (2003); [d] population-weighted average, 2005 population data from OECD Health Data (2010).*

For instance, based on Table 1, the average direct cost of a cardiac hospital admission is:

8.5 days x € 373= € 3,171

and the corresponding indirect cost related to work loss is:

2 x 8.5 days x € 73= € 1,241.

Overall, the unit economic value related to a cardiac hospital admission is € 4,412.

For city-specific valuation, the last two columns of Table 1 provide average hospitalisation costs computed following the same rationale but using country-specific average lengths of stay, cost per day of hospitalization and daily work loss.

Valuation of the benefits of EU legislation to reduce the sulphur content of fuels

The legislation has two potential effects on mortality: short-term and long-term. It has been decided that, to take a conservative standpoint, mortality effects will be considered as short-term effects. Consequently, *a VOLY of €86,600 is applied to each premature deaths to compute the benefits of the legislation.* The economic evaluation thus constitutes a lower bound of the mortality benefits of the legislation.

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