Aphekom

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

Local city report

DUBLIN

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Acronyms

APHEIS: Air Pollution and Heath, a European Information System (www.apheis.org)

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

HIA: health impact assessment

O_3: Ozone

PM_{10}: Particulate matter with an aerodynamic diameter <10 µm

$PM_{2.5}$: Particulate matter with an aerodynamic diameter <2.5 µm

PM: Particulate Matter (generic term for particles irrespective of size)

SO_2: Sulphur Dioxide

VOLY: Value of Life Year

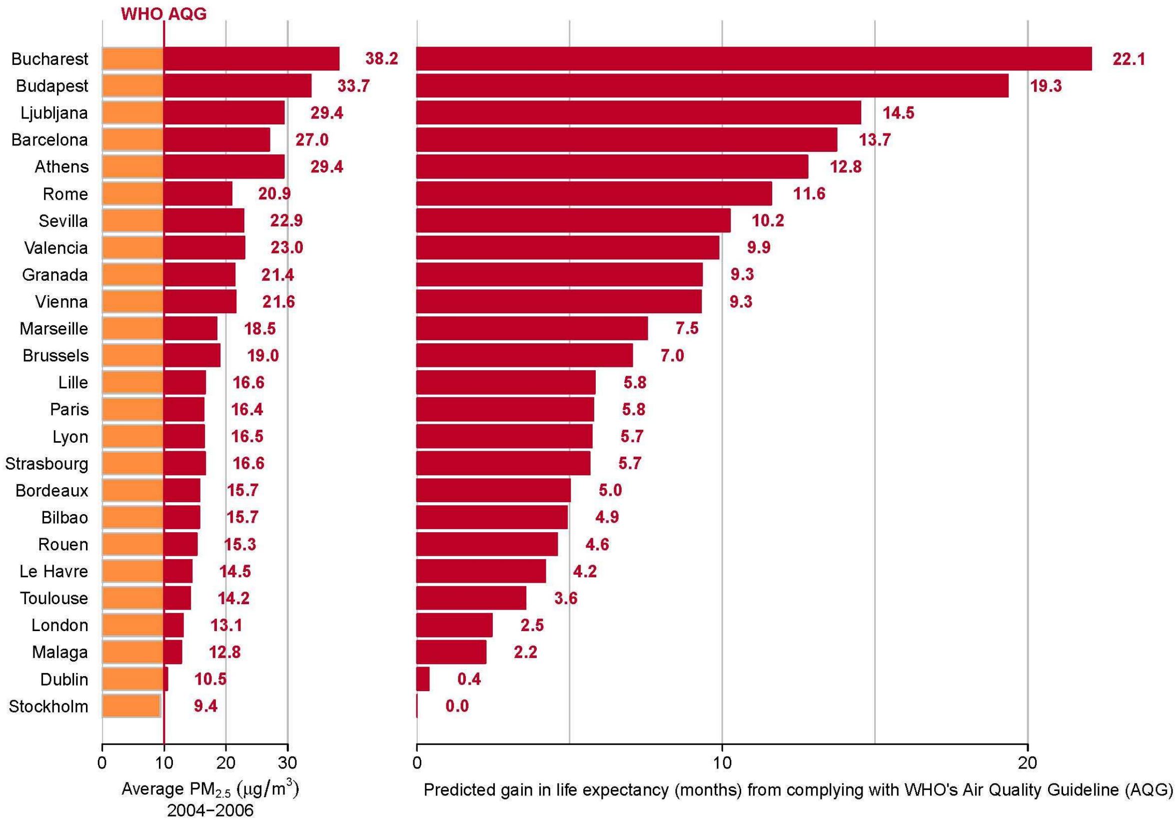
WHO: World Health Organisation

Summary

The Aphekom study was a multi-centre project funded by the European Commission (Grant Agreement: 2007105) with the aim of calculating, using standardised statistical techniques, the benefit to human health of reductions in air pollution. The project comprised investigators from 25 European cities including Dublin. Data on mortality in Dublin from 2004 to 2006 were used to assess potential benefits of reductions in PM_{10}, fine particles ($PM_{2.5}$) and ozone under a number of scenarios.

A decrease in long-term average PM_{10} concentrations by 5µg/m^3 has the potential to reduce the annual number of deaths attributable to PM_{10} by 2.4/100,000 of the population over the age of 30 years under the scenario. For $PM_{2.5}$ reductions in concentrations by 5µg/m^3 could reduce attributable mortality by 42/100,000.

Across the 25 European cities the benefits of reducing levels of $PM_{2.5}$ fine particles (WHO's annual air-quality guideline) could add up to an additional 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 across the 25 European cities 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. The results for $PM_{2.5}$ are summarised in the figure below:



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)

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

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, Bucharest, Budapest, Dublin, Granada, Le Havre, Lille, Ljubljana, Dublin, Lyon, Malaga, Marseille, Paris, Rome, Rouen, Seville, Stockholm, Strasbourg, Toulouse, Valencia and Vienna. Each participating centre collated data on health and air pollution using a standardised data collection protocol. These data were analysed centrally using a standard statistical protocol to provide city specific results as well as project-wide results. The project assessed the potential benefits of reductions in ozone and PM on both short and long-term impacts on mortality and hospital admissions in populations 30 years of age and older.

1.1. Description of the study area for Dublin

Dublin is the capital and main administrative area for Ireland. It is situated on the east coast of Ireland and is the major population centre in the country. It also has a busy port through which a significant portion of imports/exports for the whole of the country travel.
Dublin has what is described as a temperate climate, with prevailing SW winds. The population of the Greater Dublin area is over 1 million people (13% older than 65 years old), however only the main city area has been considered for this study with a total area of 114.99 km^2.
Dublin has a temperate climate, meaning that it is not prone to extremes of hot or cold. Because Ireland is on the Atlantic, it is one of the wettest areas in Europe. It is also quite windy, and thus conditions conducive to pollution formation do not occur too often. With that said, there are occasions of high pressure when cold frosty periods can develop in winter and give rise to elevated pollution levels.

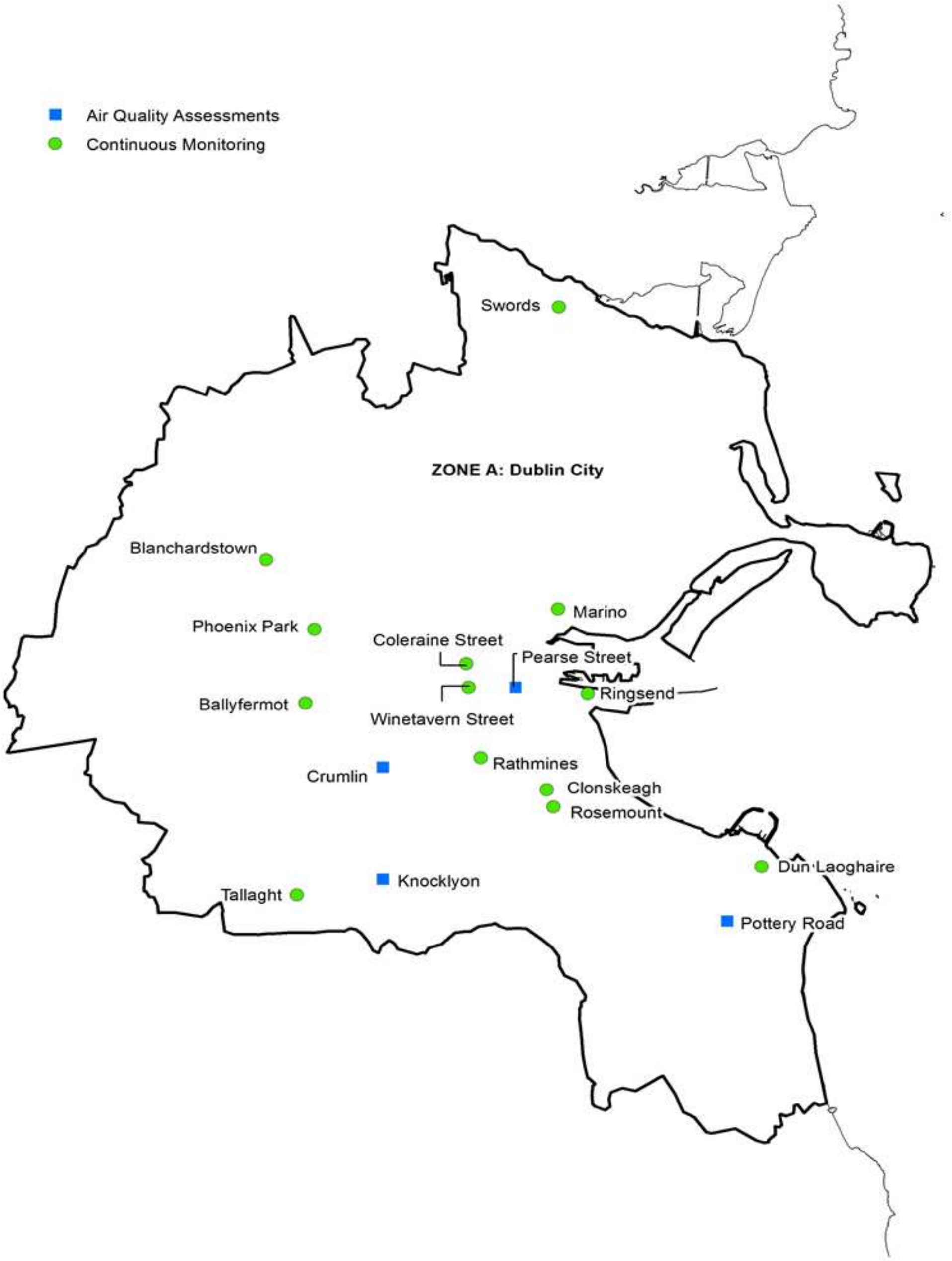


Figure 1.1 – Map of Dublin City with local air quality assessment points and continuous monitoring stations

(http://www.epa.ie/whatwedo/monitoring/air/data/dub/)

1.2 Climatology

The dominant influence on Ireland's climate is the Atlantic Ocean. Consequently, Ireland does not suffer from the extremes of temperature experienced by many other countries at similar latitude. The warm North Atlantic Drift has a marked influence on sea temperatures. This maritime influence is strongest near the Atlantic coasts and decreases with distance inland. The hills and mountains, many of which are near the coasts, provide shelter from strong winds and from the direct oceanic influence. Winters tend to be cool and windy, while summers, when the depression track is further north and depressions less deep, are mostly mild and less windy (http://www.met.ie/climate-ireland/climate-of-ireland.asp, Accessed: 4th April 2011).

The annual mean temperature in Dublin is 9.6℃ with the highest and lowest monthly averages in July with 15.1℃ and January/February with 5.0℃ respect ively. Dublin's climate receives an average of 732.7 mm of rainfall per year. Global Solar Radiation in Joules/cm^2 in Dublin ranges between 5137 [J/cm^2] in December and 52826 [J/cm^2] in July with an annual average of 331683[J/cm^2].

All means presented here are for the period 1961-1990 except solar radiation 1981-1990 measured at the Dublin Airport station.
(Source: http://www.met.ie/climate/monthly-data.asp?Num=532 , Accessed: 4th April 2011)

1.2 Population in the study area

A detailed overview on characteristics of the study population in Dublin in the year 2006 is shown in Table 1.1 and Table 1.2 and as well in Figure 1.2.

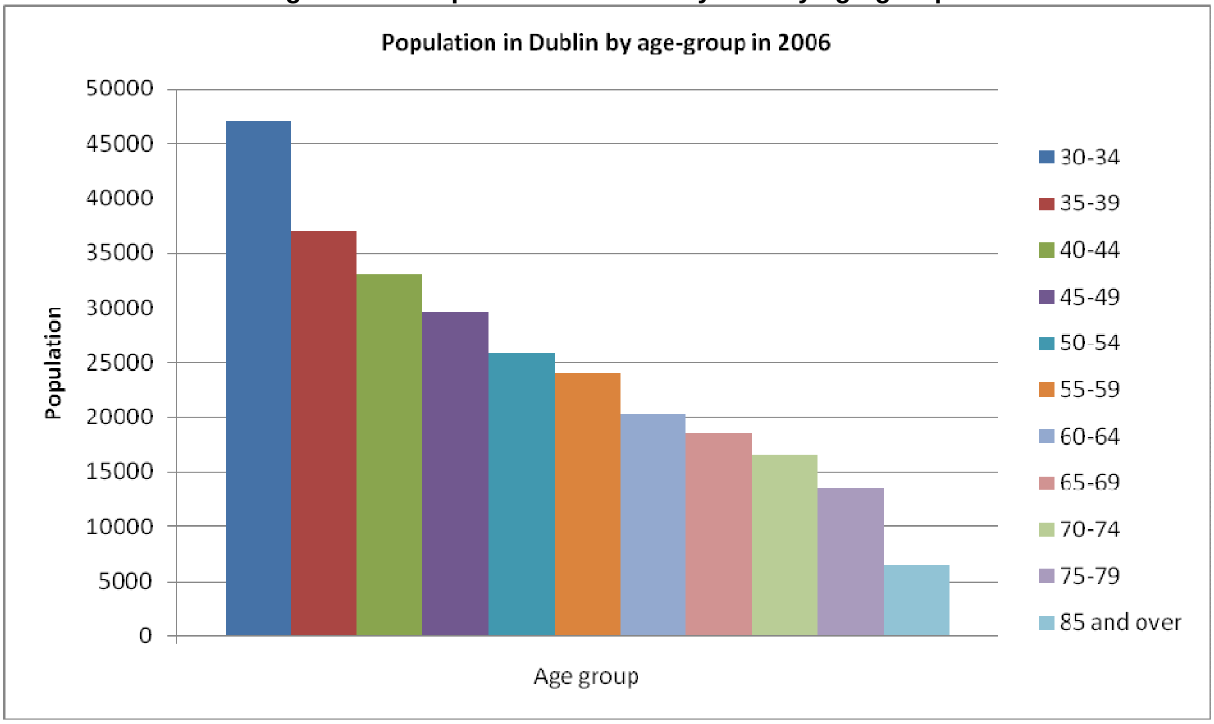
Table 1.1 – Population in the study area in 2006
(http://census.cso.ie/Census/TableViewer/tableView.aspx)

0-14	75854
15-64	366,089
65 and over	64268
All ages	506,211

Table 1.2 – Population by gender and by age group in the study area in 2006
(http://census.cso.ie/Census/TableViewer/tableView.aspx**)**

Age group	**Population**		
	male	**female**	**ALL**
30-34	24358	22655	47013
35-39	19016	18014	37030
40-44	16536	16443	32979
45-49	14658	14890	29548
50-54	12853	12977	25830
55-59	11871	12165	24036
60-64	9819	10531	20350
65-69	8559	9942	18501
70-74	7171	9354	16525
75-79	5370	8169	13539
80-84	3157	6068	9225
85 and over	1728	4750	6478
TOTAL	135,096	145,958	281,054

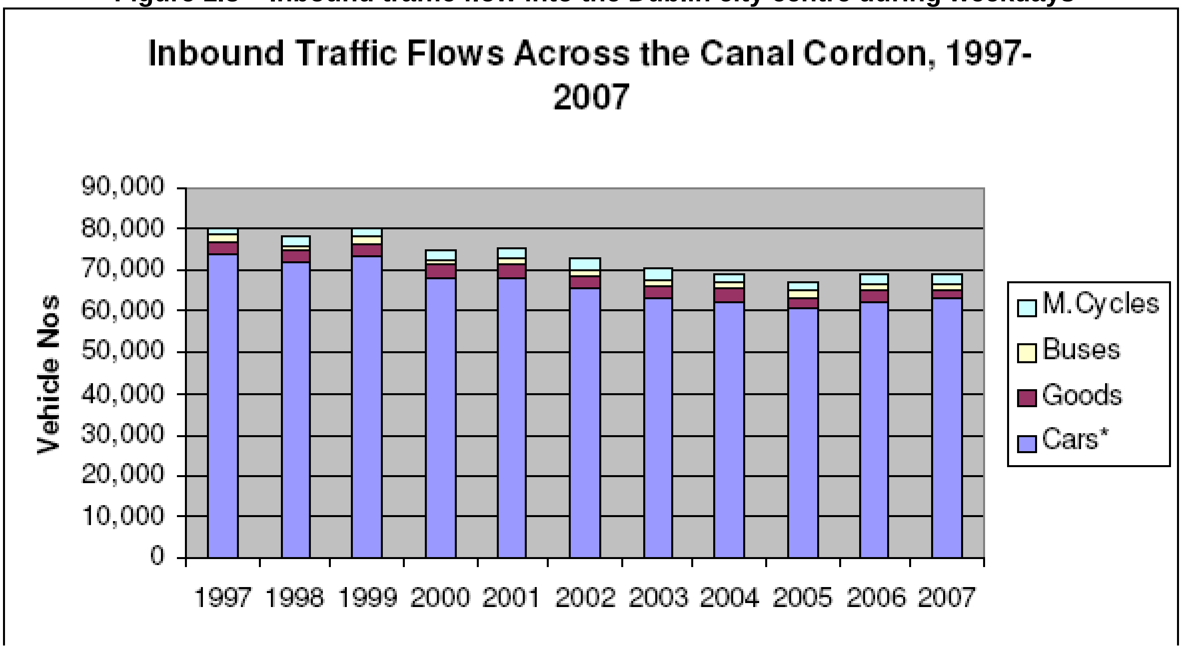
Figure 1.2 – Population in the study area by age-group



1.3 Commuting

Based on traffic counts in November each year undertaken by the Dublin City Council including all roads crossing the Royal Canal and Grand Canal as well as other roads approaching the city centre from the west were surveyed. The count was undertaken over a 3hour period on two separate weekdays (Tuesday, Wednesday or Thursday). Figure 1.3 outlines the characteristics of the vehicle fleet of inbound traffic into the Dublin city centre overtime showing that cars (*including taxis) are the main proportion (over 90%) of the inbound traffic flow. Over the entire period from 1997-2007, traffic numbers have fallen by 14% (DTO road users monitoring report, 2008).

Figure 1.3 – Inbound traffic flow into the Dublin city centre during weekdays



An analysis of 2002 Census travel data undertaken by the Dublin Transport Office showed significant increases in the use of public transport for trips into Dublin City Centre. In the Hinterland Area of the Greater Dublin Area (GDA), however, this increase in the use of public transport was offset by big increases in car ownership and car trips. Overall, a proportion of about 60% of people in the GDA used their cars to get to work. In addition it was reported that the number of bus passengers had increased by 18498 (60.57%) from November 1997 to November 2003. Furthermore the analysis also showed the importance of walking as a mode of travel, with over 12% of people walking to work in the GDA (Dublin Transportation Office Annual Report & Accounts 2004).

1.4 Sources of air pollution and exposure data

There are no major industries in Dublin making significant contributions to air pollution. Since the introduction of the coal ban in 1990, the biggest source of particulate pollution in the Dublin area can be attributed to road traffic. Dublin does not have a metro system and is highly reliant on road transport, buses and private cars for transport. This coupled with large numbers of goods vehicles travelling to the port are the major contributors to particulate pollution levels. The climate normally assists in dispersing pollutants. For example in Figure 1.1 it can be seen that the air quality in Dublin in relation to $PM_{2.5}$ levels is one of the best in Europe.

Table 1.3 gives an overview of the air pollution emissions from the main emission sources in Ireland in 2004.

Table 1.3 - Main sources of air pollution in Ireland in kt/year in 2004
(Central Statistics Office, Ireland, May 2006)

Pollutant	**Transport** (Includes both the Transport sector and road transport activities carried out in all other sectors)	**Residential**	**Industry** (excluding power, water, fuel)	**Fuel, Power, Water**	**Agriculture, Forestry, Fishing**	**Services** (excluding transport)
SO_2	2.5	22.1	19.8	3.3	1.9	20.2
NO_2	1.4	1.2	0.5	0.1	25.2	0.9
Primary PM_{10}	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Primary $PM_{2.5}$	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.

1.5 Exposure data

Air quality measurements were obtained from the Irish Environmental Protection Agency's (EPA) SAFER database that provides links to archives of various air pollutants monitoring data for download by public users:
http://erc.epa.ie/safer/dataAndResources/publiclyAvailableDatasets.jsp (Accessed: 4th April 2011).

For this study, daily average concentrations for the period 2004-2006 were collected from 1 urban background monitoring station in Rathmines, Dublin 6, for Ozone (O_3) and 2 urban background monitoring stations for PM_{10} (using gravimetric measurement method) in Ballyfermot, Dublin 10, and Marino.
The Rathmines site is located in Wynnefield Road in the southern suburb of Rathmines, about 3 kilometres from the city centre (http://www.epa.ie/whatwedo/monitoring/air/data/d/r/, Accessed: 4th April 2011).
The Ballyfermot monitoring site is located in the public library in Ballyfermot being operated by the Dublin City Council (http://www.epa.ie/whatwedo/monitoring/air/data/d/b/, Accessed: 11th April 2011).
The Marino monitoring site is located in the yard of the Fire Brigade training centre in the North-Eastern suburb of Marino operated by Dublin City Council
(http://www.epa.ie/whatwedo/monitoring/air/data/d/m, Accessed: 11th April 2011). PM_{10} was measured at Marino until 31 December 2008.

Summary statistics for daily concentrations are given below in Table 1.4. In addition Figure 1.3 and Figure 1.4 show daily mean urban background PM_{10} and O_3 concentrations in Dublin over the study period respectively.

Table 1.4 Daily mean urban background levels, standard deviation and 5th and 95th percentile for air pollutants (2004 - 2006)

Pollutant	Measuring station	Annual mean (μg/m^3)	Standard deviation (μg/m^3)	*5th percentile* (μg/m^3)	*95th percentile* (μg/m^3)
Ozone (daily 8h-max)	Rathmines, Dublin 6	*55.7*	*9.29*	*27*	*78*
PM10 (daily average)	Ballyfermot, Dublin 10, and Marino	*15.0*	*16.54*	*6*	*34*
PM2.5 (daily average)*	Ballyfermot, Dublin 10, and Marino	*4.5*	*2.79*	*2*	*10*

*** conversion factor PM_{10} to $PM_{2.5}$ = 0.3**

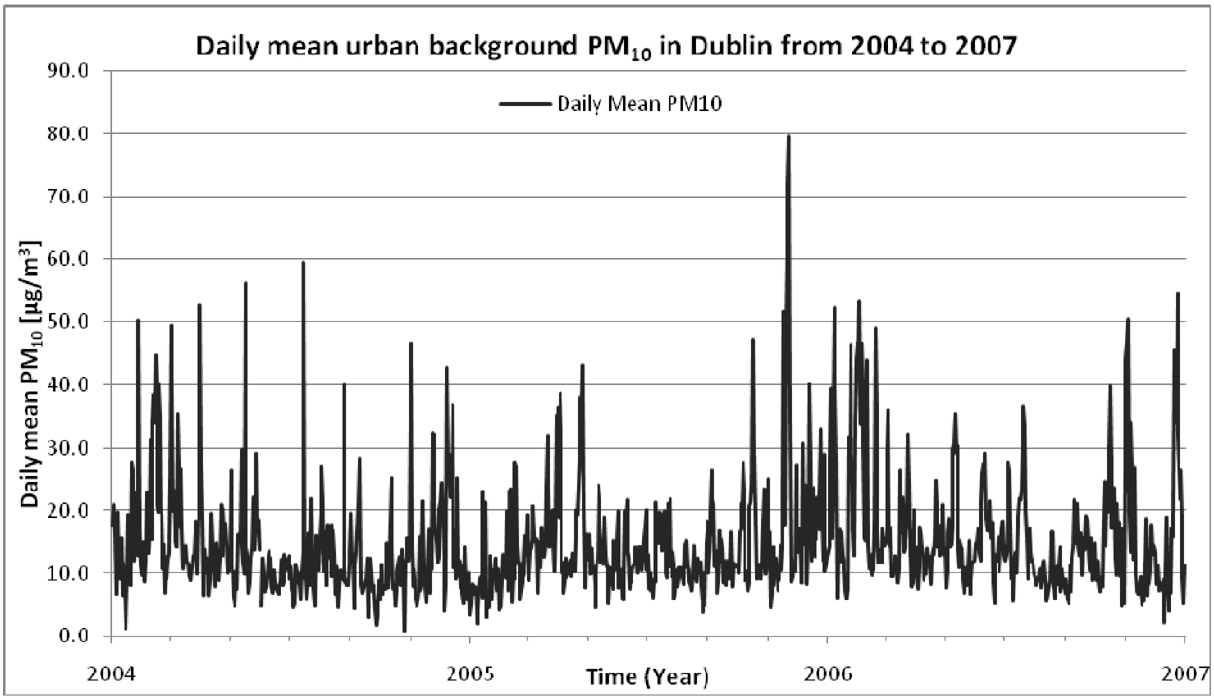


Fig.1.3: Daily mean urban background PM_{10} in Dublin from 2004 to 2006

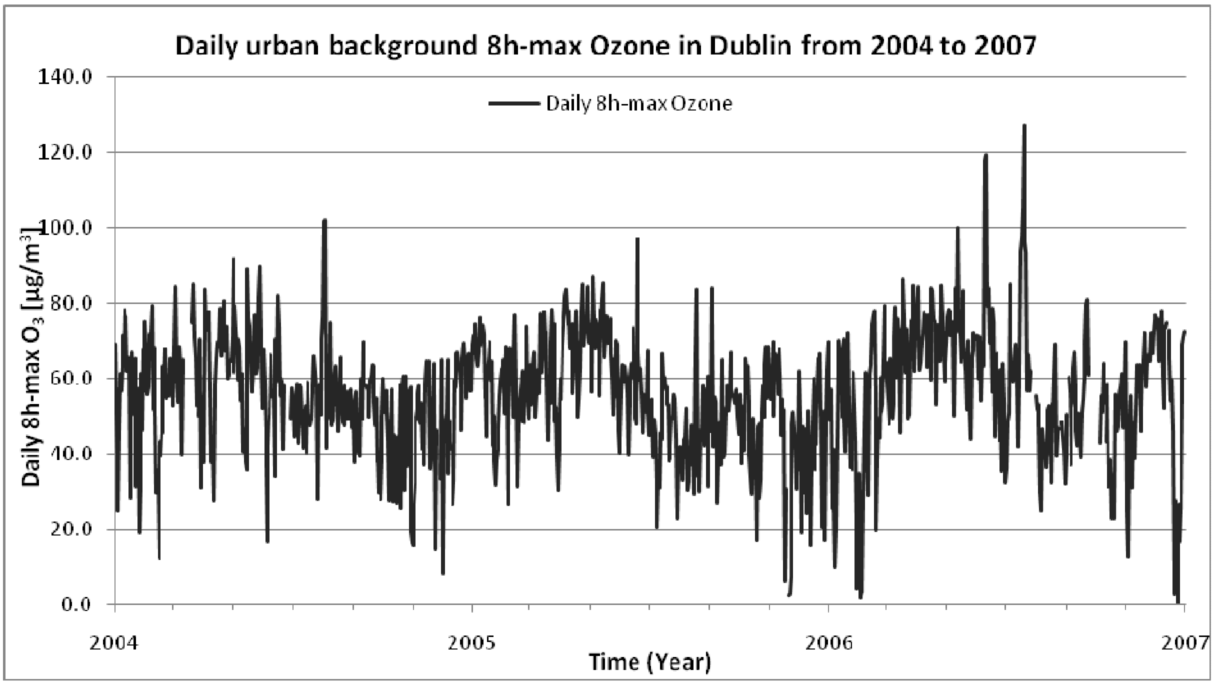


Fig.1.4: Daily 8h-max urban background O_3 in Dublin from 2004 to 2006

1.6 Health data

Mortality data on a daily basis is extracted from data for the whole country, supplied by the Central Statistics Office (CSO). The most recent year for which such data is available is 2007. Mortality for Dublin city (Dublin County Borough) was extracted from the mortality files and sorted by day of death, and by cause of death (according to ICD-9). Only non-accidental deaths were considered.

Table 1.5 - Annual mean number and annual rate per 100 000 of deaths 2004 – 2006 using population data from 2006

Health outcome	ICD-9	Age	Annual mean number	Annual rate per 100 000
Non-external mortality* from ALL causes	**000-999**	> 30	3937	1401
mortality from RESPIRATORY causes	**460-519**	> 30	626	223
mortality from CARDIOVASCULAR causes	**390-459**	> 30	1447	515

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

1.7 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. It is important to note that the HIA findings for the different air pollutants cannot 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.

1.7.1 Short-term impacts of PM_{10}

For PM_{10}, we first considered a scenario where the annual mean of PM_{10} is decreased by 5µg/m^3, and then a scenario where the PM_{10} annual mean is decreased to 20µg/m^3, the WHO annual air quality guideline (WHO-AQG). The results are presented in Tables 4 and 5 and illustrated in Figure 5.

Over the period of time under consideration Dublin reported a mean PM_{10} of 15µg/m^3 so a reduction scenario meeting a target value of 20µg/m^3 is non-applicable as this has already been achieved.

Table 1.6 - Potential benefits of reducing daily PM_{10} levels on total (non-external) mortality

Scenarios	Annual number of deaths avoided	Annual number of deaths avoided per 100 000
Decrease by 5 µg/m^3	12.1	2.4
Decrease to 20 µg/m^3 *	n.a.	n.a.

***Levels in Dublin already below 20µg/m^3**

1.7.2 Short-term impacts of ozone

For ozone, WHO set two guideline values for daily the maximum 8-hours mean. 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 100 µg/m^3.

We first considered scenario 1 where all daily values above 160µg/m^3 were reduced to WHO-IT (160 µg/m^3), then scenario 2 where all daily values above 100µg/m^3 were reduced to WHO-AQG (100 µg/m^3), and lastly a scenario where the daily mean is decreased by 5µg/m^3. Results for each of these scenarios are presented in Tables 1.7.

The first proposed scenario was found to be non applicable to the O_3 data of Dublin as none of the measured 8h-max O_3 values were above 160µg/m^3. The maximum value recorded of 8h-max O_3 was 127µg/m^3. Therefore, results are only presented for scenario 2.

Table 1.7 - Potential benefits of reducing daily ozone levels on total (non-external) mortality

Scenarios	Annual number of deaths avoided	Annual number of deaths avoided per 100 000
8h-max daily Values >100 µg/m^3 = 100 µg/m^3	**0.09**	**0.02**

1.7.3 Long-term impacts of $PM_{2.5}$

For $PM_{2.5}$, we first considered a scenario where the $PM_{2.5}$ annual mean is decreased by 5µg/m^3, and then a scenario where the $PM_{2.5}$ annual mean is decreased to 10µg/m^3 (WHO AQG). Results for each of these scenarios are presented in Tables 1.8 & 1.9.

Over the period of time under consideration Dublin reported a dialy mean PM2.5 concentration of 4.5(µg/m3) so a reduction scenario meeting a target value of 10(µg/m3) is non-applicable as this has already been achieved.

Table 1.8 - Potential benefits of reducing annual $PM_{2.5}$ levels on total non-external mortality for age >30

Scenarios	Annual number of deaths avoided	Annual number of deaths avoided per 100 000	Gain in life expectancy (months)
Decrease by 5 µg/m^3	119	42.34	0.32
Decrease to 10 µg/m^3	n.a.	n.a.	n.a.

Table 1.9 – Potential benefits of reducing annual $PM_{2.5}$ levels on total cardiovascular mortality for age >30

Scenarios	Annual number of attributable deaths avoided	Annual number of attributable deaths avoided per 100,000
Decrease by 5 µg/m^3	79.7	28.37
Decrease to 10 µg/m^3	n.a.	n.a.

1.7.4 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 differ depending on the short- or long-term nature of the exposure to air pollution (see Appendix 2). For attributable deaths avoided due to short-term exposure to pollution the monetary cost was estimated at €86,600. Hence for a reduction of 5µg/m^3 in average PM_{10} levels in Dublin the estimates saving is approximately €1,048,000.

Savings arising from long term exposure were higher at €1,655,000 per death. Hence for a reduction of 5µg/m^3 in average $PM_{2.5}$ levels in Dublin the estimates saving is approximately € 132m.

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.

1.7.5 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 Dublin 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.

Chapter 2. Health Impacts of Implemented Policies in Air Pollution

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.
This analysis 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.

2.1 Air quality analysis

The general decreasing trend in daily urban background (UB) SO_2 concentrations that has been observed across all centres (only Paris was taken as a representative for the 9 French centres) over the time period of the study is illustrated in Figure 2.1. Overall there was no clear step change in SO_2 concentrations after implementation of the Directives; rather a gradual decline in SO_2 levels was observed. It has not been possible to directly attribute these changes in SO_2 levels to the legislation, as we did not observe any step change in SO_2 levels coincident wit the implementation dates of the legislation.

Furthermore city specific observations for Dublin of decreasing UB SO_2 levels are presented in Figure 2.2 showing monthly averages and in Figure 2.3 showing seasonal averages of UB SO_2 (please note change in scaling compared to Fig. 2.1).

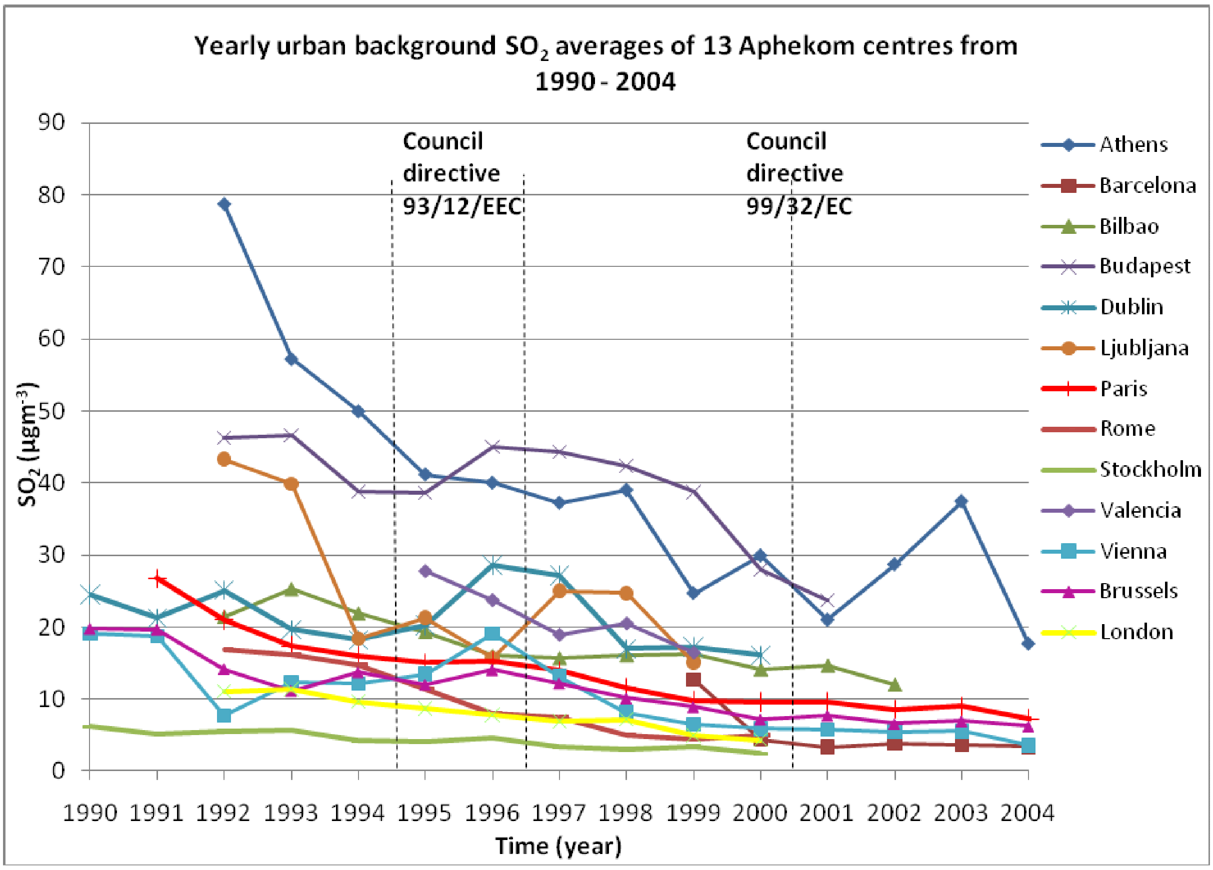


Figure 2.1: Plot of yearly urban background SO_2 averages of 13 Aphekom centres from 1990 – 2004

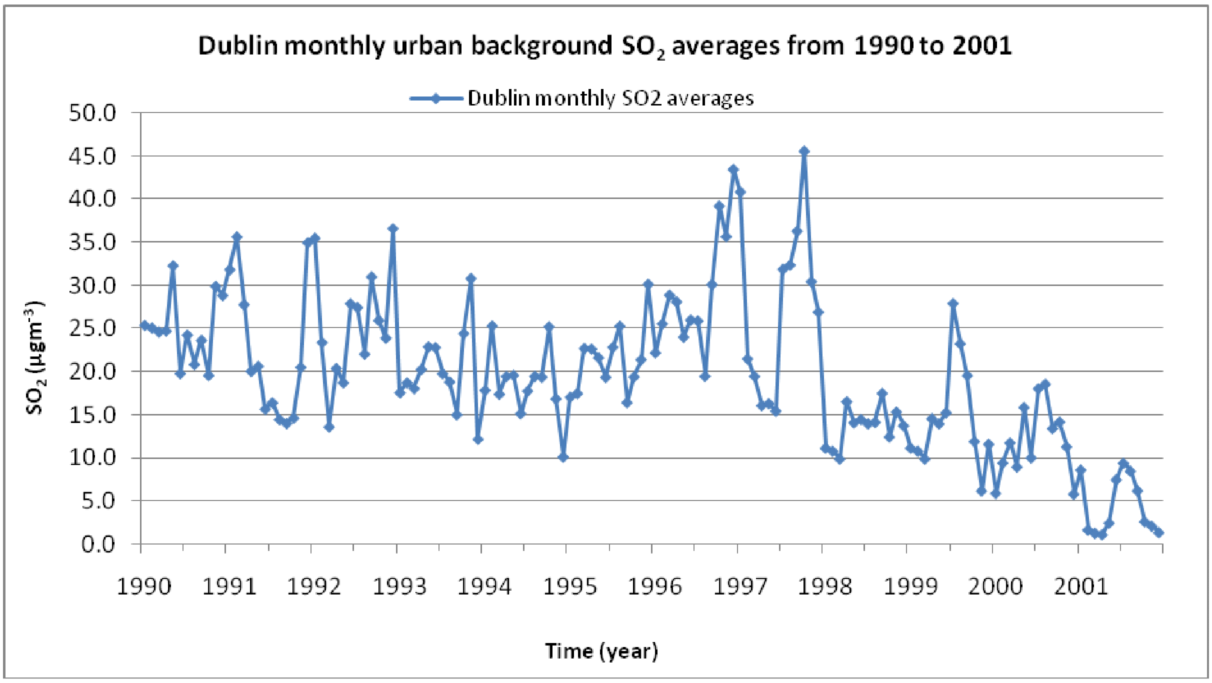


Figure 2.2: Plot of monthly urban background SO_2 averages for Dublin from 1990 – 2001

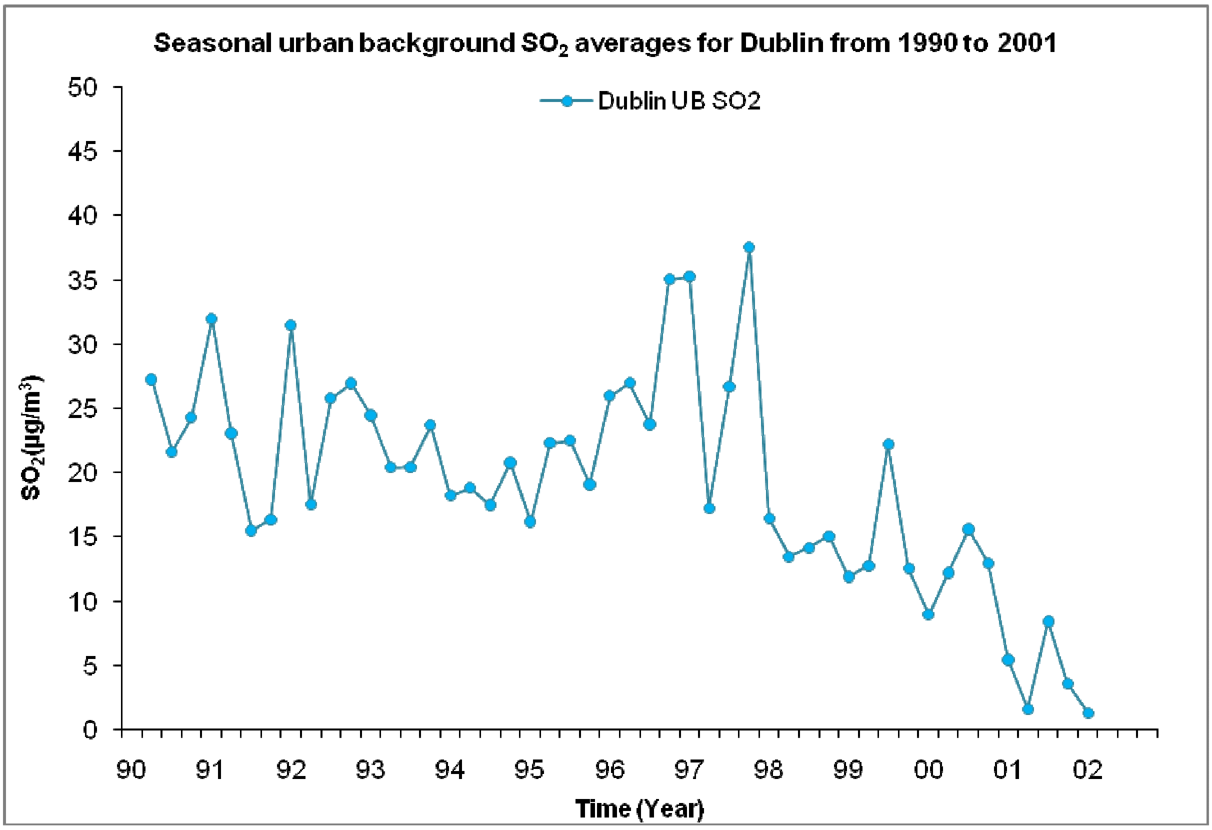


Figure 2.3: Plot of seasonal urban background SO_2 averages for Dublin from 1990 – 2001

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. Dublin observed a slight peak in December 1995 and higher peaks in the winter of 1996/7 and the winter in the following year.
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.

Furthermore an analysis of hourly SO_2 data obtained from a number of centres involved in the Aphekom project was conducted. This included the generation of individual diurnal SO_2 profiles in order to identify city specific patterns including source appointment, i.e. traffic, heating, shipping and industrial sources and quantification and to track changes over time.

Figure 2.4 and Figure 2.5 show plots of hourly SO_2 data from Dublin showing seasonal plots for winter (Fig.2.4) and summer (Fig 2.5) for an urban background station for the years 2002 to 2008. There was no hourly data available prior to this time period.
Traffic related SO_2 peaks were observed throughout all seasons for the morning (peaking btw. 7-9am) and evening rush hour (peaking around 5-7pm). In addition to that the high winter readings around mid-night suggest heating systems.
In Fig. 2.4 the observed winter SO_2 levels in 2002 are markedly higher than later years and the peak patterns resemble the pattern found in the following years. The high values found in the evening until morning hours suggest that the observed high SO_2 levels during those hours were due to heating related emissions due to the cold weather. In comparison to following years no high SO_2 levels were

observed for the summer 2002. Overall a decreasing trend in SO_2 levels overtime regarding the heating related emissions during night-time has been observed. On the other hand no obvious decrease has been observed looking at most likely traffic related SO_2 emissions, which can be clearly seen in the summer plots (Fig 1.5) where SO_2 levels stay quite constant during the whole day for the majority of the plotted years, ranging between ~4.0 and 0.5µg/m^3 without a clear trend throughout the years. It is not clear, if these SO_2 levels were decreasing and increasing due to high sulphur content in diesel fuel for vehicles or due to changes in the vehicle fleet, i.e. increasing/decreasing number of vehicles or of diesel vehicles, changes in commuting behaviour etc..
The very low and almost constant SO_2 concentration throughout the entire day in summer 2008 ranging between 0.5 to 0.8µg/m^3 was well below the detection limit of the measurement instruments which is ~ 0.5ppb which is equivalent to 1.3µg/m^3. According to information received from the Irish EPA, values below the detection limit should be interpreted with caution as the purpose of the measuring station is not to accurately measure very low levels, but to compare observed values against the EU health limit values of 125µg/m^3 (annual) and 350µg/m^3 (hourly). A possible explanation for the drop in SO_2 levels in 2008 below detection levels of the measuring equipment may in part be due to the financial crisis/recession, if SO_2 has industrial origin or traffic related origin.

The shifts in SO_2 maxima between winter and summer are partially due to artificial changes in switching from summer to winter time and vice versa.

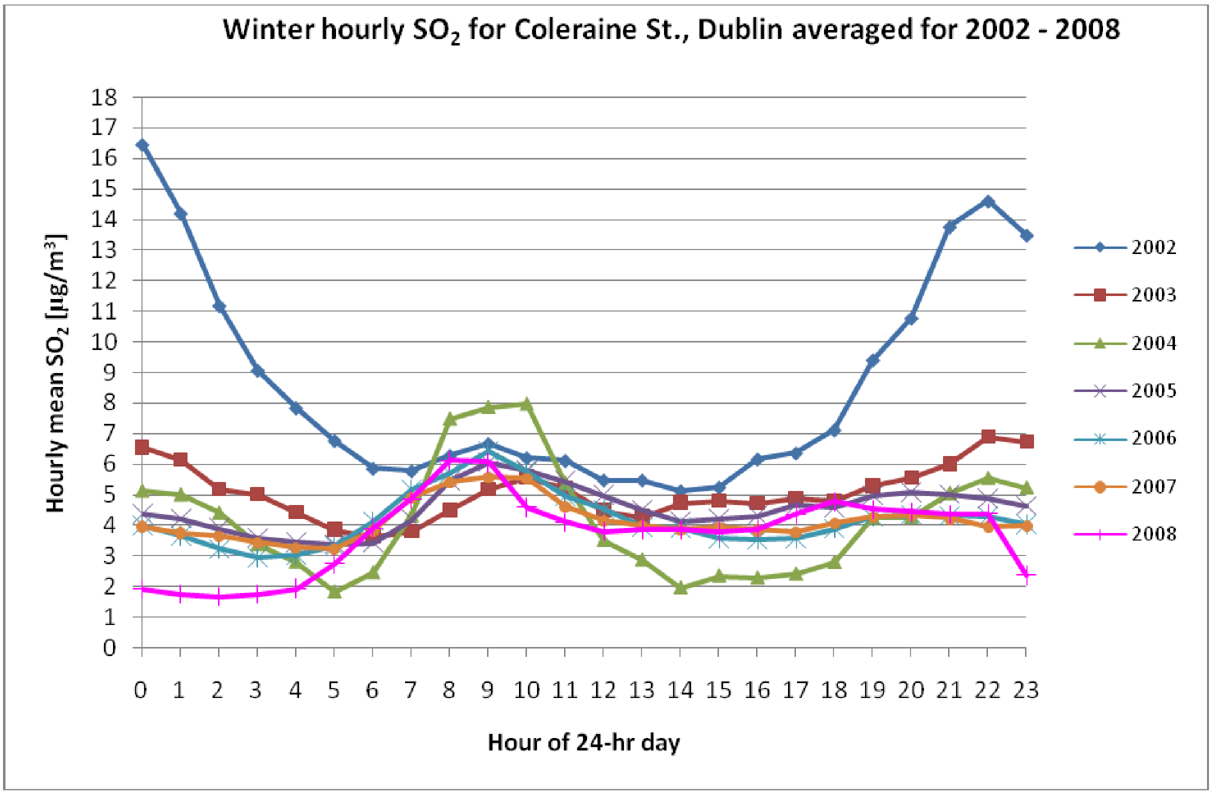


Figure 2.4: Diurnal plot of winter hourly SO_2 for a urban background station in Dublin from 2002-2008

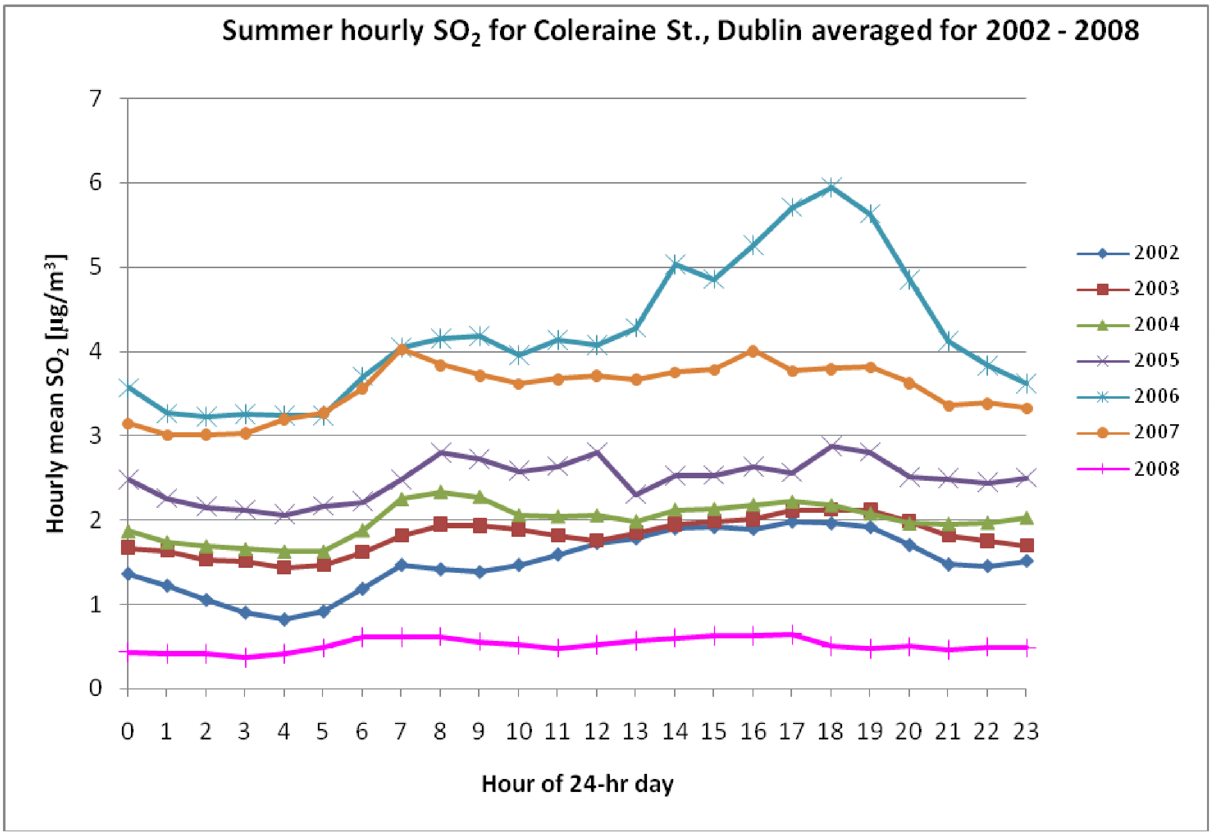


Figure 2.5: Diurnal plot of summer hourly SO_2 for a urban background station in Dublin from 2002-2008

Figure 2.6 to Figure 2.8 show plots of hourly SO_2 data from Dublin by weekday for an urban background station for the years 2002, 2004 and 2008 respectively.

Again a general downwards trend overtime has been observed throughout the years. Higher SO_2 levels peaking around midnight indicate emission levels due to space heating. Those heating related emissions show a marked decrease possibly indicating a shift in fuel usage with levels in 2002 as shown in Fig. 2.6 ranging around 4-8µg/m^3 and dropping to 2.5-0.58µg/m^3 in 2008. This corroborates with findings from the seasonal plots. Furthermore a decrease for daytime SO_2 levels has been noted, which would be most likely related to traffic related emissions as a peak reflecting the morning and evening rush hour can be observed with varying intensity throughout the years.

In the weekday specific plots a stretched out peak on Thursdays was observed for the majority of the years as seen in Fig.2.6 and 2.7. A possible explanation for that would be a reflection of higher traffic related values due to late night shopping (Thursday shops are open until 9pm in Dublin).

Furthermore throughout all plots by weekday lower SO_2 levels were observed during daytime at the weekend (Saturday and Sunday) compared to the other weekdays, which most likely reflects the missing traffic volume due to commuters driving to and from work during the week.

Figure 2.6 and 2.7 show that mean difference between minimum Sunday and maximum weekday values for SO_2 at rush hour was approximately 6µg/m^3 for the years 2002 and 2004. In contrast to that in 2008 (Figure 2.8) where levels are very low ranging between 2.9 and 0.4µg/m^3, the mean difference was approximately 2µg/m^3.It has to be noted that documented SO_2 weekend levels in 2008 again were below the detection limit of the measurement equipment and hence have to be interpreted with caution. Background levels fell overtime from 2µg/m^3 in 2002/4 to 0.5 µg/m^3 which again could be due to the economic recession in 2008 and the associated "death of the Celtic Tiger" (a term describing the extraordinary economic growth that Ireland experienced 1995 to 2007).

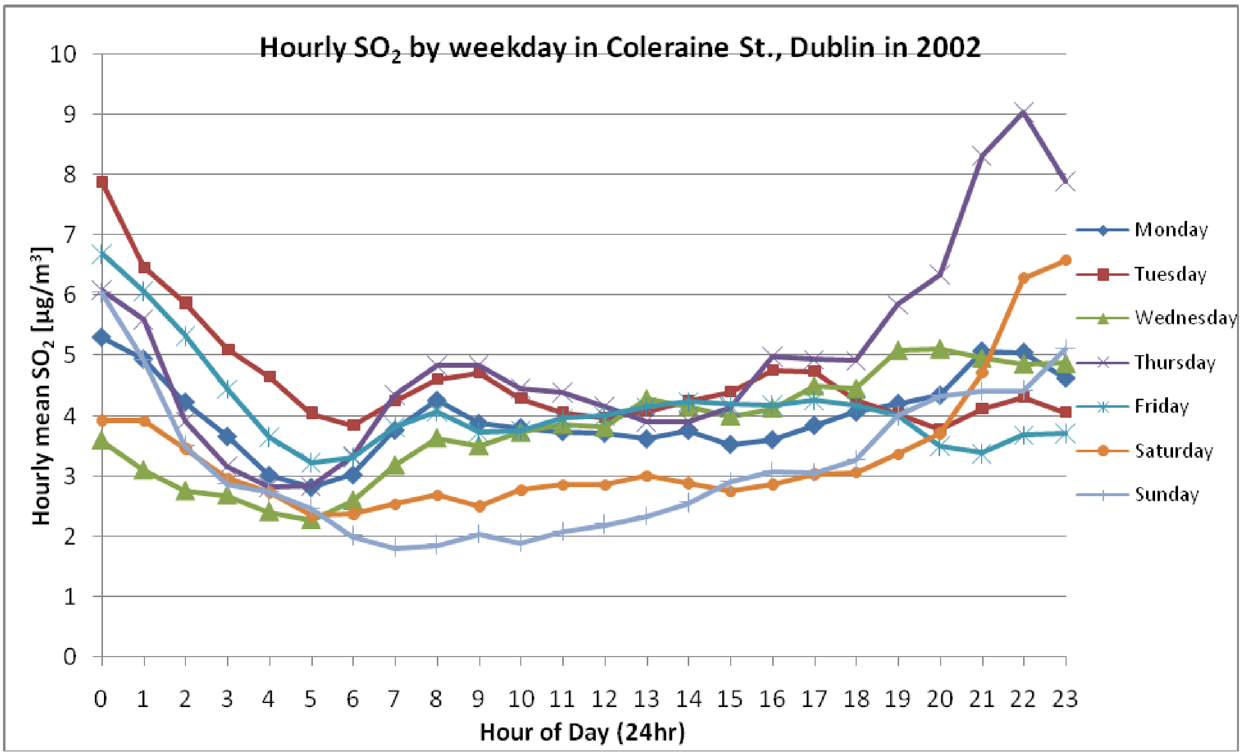


Figure 2.6: Diurnal plot of hourly SO2 by weekday for an urban background station in Dublin in 2002

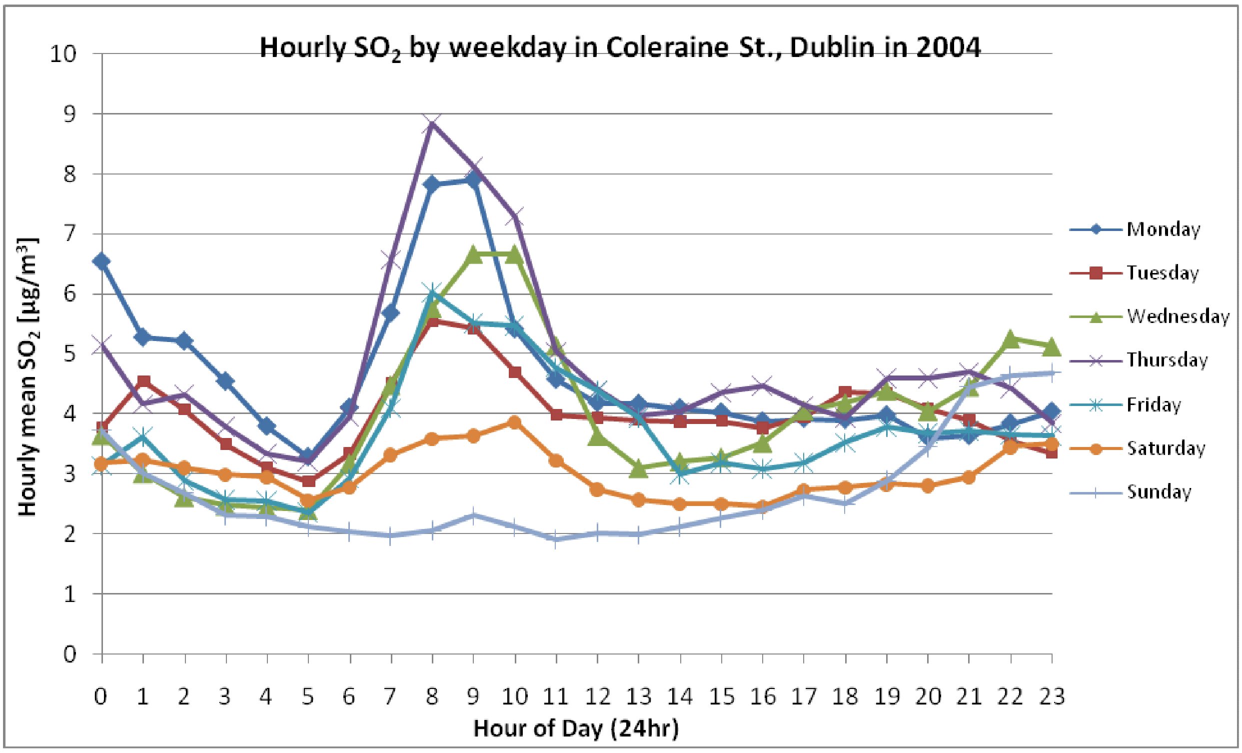


Figure 2.7: Diurnal plot of hourly SO_2 by weekday for an urban background station in Dublin in 2004

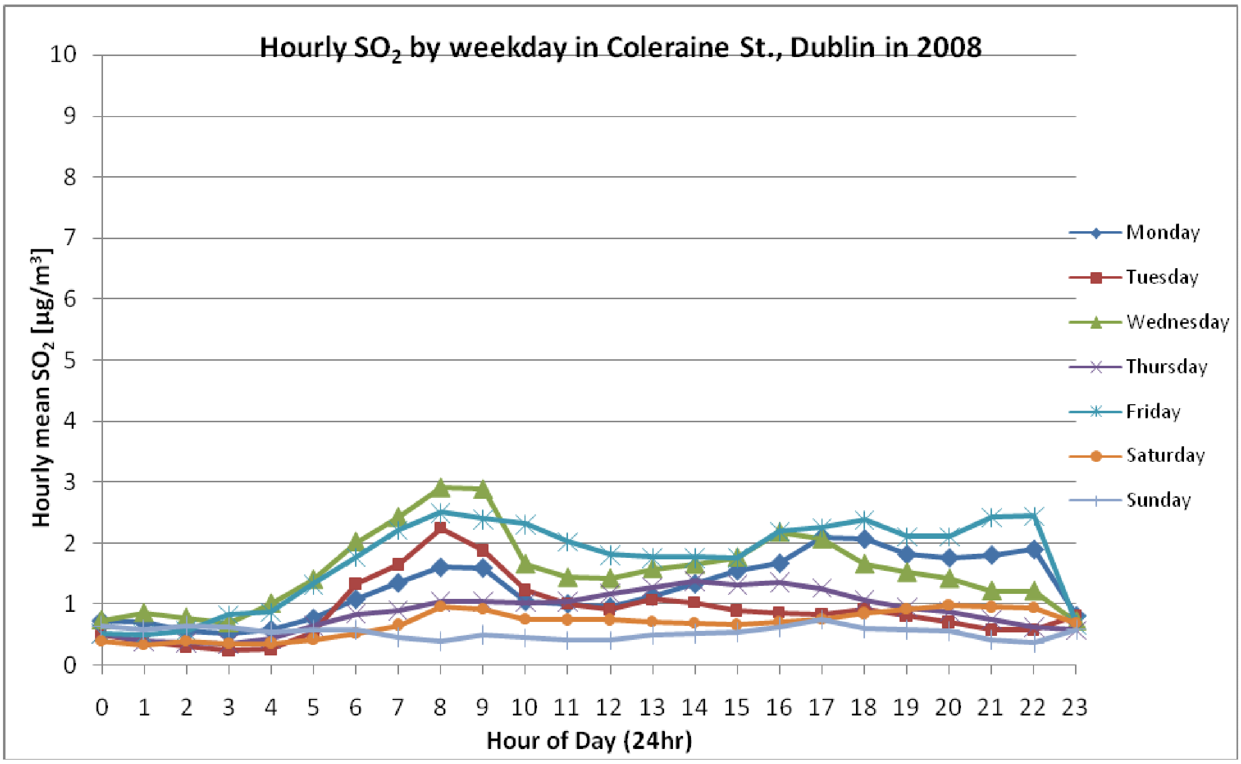


Figure 2.8: Diurnal plot of hourly SO_2 by weekday for an urban background station in Dublin in 2008

2.2 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 analysis showed that an increase of 10µgm^{-3} in SO_2 levels was associated with an overall (pooled) increase in daily all-cause (0.53%), respiratory (0.49%) and cardiovascular (0.72%) mortality. Intuitively one would expect that a decrease in daily SO_2 levels would result in a decrease in daily deaths.

We defined as reference level, the SO_2 average before the first intervention, and calculated attributable deaths for each intervention period from this point.

The health data analysis showed no evidence of change of slope in the dose-response curve after implementation of the legislations. Therefore the estimated decreases in mortality are not due to a change in the relationship and cannot be directly ascribed to the implementation of the SO_2 Council Directives, but are rather due to the overtime decline in levels of the pollutant.

Assessing the time period after the implementation of the first stage in 1994 a reduction in annual deaths by 639 deaths from all causes, by 47 deaths from respiratory and by 361 deaths from cardiovascular causes was observed compared to the baseline period prior to October 1994 with no directive being implemented.

Assessing the time period after the implementation of the 2nd stage of the 93 Council Directive in 1996 annual deaths were reduced 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.

Assessing the time period after the implementation of the 3rd stage in 2000 a reduction in annual deaths by 1616 deaths from all causes, by 127 deaths from respiratory and by 889 deaths from cardiovascular causes was observed compared to the baseline period with no directive being implemented.

On a city specific level for Dublin:

Assessing the time period after the implementation of the first stage in 1994 a reduction in annual deaths by -1 death from all causes, by 0 deaths from respiratory and by -1 death from cardiovascular causes was observed compared to the baseline period prior to October 1994 with no directive being implemented.

Assessing the time period after the implementation of the 2nd stage of the 93 Council Directive in 1996 annual deaths were reduced by 9 deaths from all causes, by 1 death from respiratory and by 5 deaths from cardiovascular causes compared to the baseline period with no directive being implemented.

Assessing the time period after the implementation of the 3rd stage in 2000 a reduction in annual deaths by 37 deaths from all causes, by 5 deaths from respiratory and by 22 deaths from cardiovascular causes was observed compared to the baseline period with no directive being implemented.

As a result on a city specific level for Dublin (summarized in Table 2.1) and overall for the 14 cities, for which all 3 time periods with respect to the implementation of the stages of the fuel legislation were assessed, it was found that the efficiency/effectiveness based on the number lives saved per year, compared to the reference period prior to October 1994, increased throughout the different time periods assessed with more lives being saved after October 1996 compared to the first time period (1994 to 1996) and with more lives being saved in the third time period assessed than in the 2nd one.

Table 2.1: Summary of lives saved per assessed time period (1-3)/intervention (and 95% Confidence Intervals) per year in Dublin for different mortality groups compared the baseline period (<01.10.1994)

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]	-1	0	-1	0	0	0	-1	0	-1
Stage 2 [≥ 01.10.1996 and <01.07.2000]	9	3	15	1	0	3	5	2	9
Stage 3 [≥ 01.07.2000]	37	13	61	5	-2	11	22	6	37

2.3 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 was decided that, to take a conservative standpoint, mortality effects would 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 3. Sharing Knowledge and Uncertainties with Stakeholders

Uncertainties perceived by scientists, policy makers and other stakeholders can undermine their confidence in the findings of HIAs. For this reason, Aphekom has developed a method that helps stakeholders 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.

Chapter 4. Overview of findings

In this report the Aphekom team has 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 Dublin 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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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 2 – Health outcome and relative risks used in the HIA

HIA	Health outcome	Ages	RR per 10 µg/m^3	Ref
Short-term impacts of PM10	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)

PM10

For PM10, we first considered a scenario where the annual mean of PM10 is decreased by 5 µg/m^3, and then a scenario where the same PM10 annual mean is decreased to 20 µg/m^3, the WHO air quality guideline (WHO-AQG).
The exposure indicator of PM10 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, Δx = 5 µg/m^3
- Scenario 2, Δx =($[PM10]_{mean}$ – 20 µg/m^3).
  Δx = 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.

The corresponding Δx for the two scenarios are;

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

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

- Scenario 2, if $[O_3]_i \geq 100$ µg/m^3, $Oi=([O_3]_i-100)$
  if $[O_3]_i<100$ µg/m^3, $Oi=0$
- Scenario 3, where the ozone yearly mean is decreased by 5 µg/m^3. Δx = 5 µg/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, Δx = 5 µg/m^3
- Scenario 2, Δx = ($[PM2.5]_{mean}$ – 10 µg/m^3)
  Δx = 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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