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ENVIRONMENT RELATED HEALTH COSTS IN FLANDERS

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Abstract

In 2007-2008, ARCADIS has conducted a study on behalf of the Flemish government, with as main objectives a review and a critical analysis of the existing calculations of environmental health costs in Flanders. This study covers the effects on human health of air pollution due to particulates and tropospheric ozone. Despite the large uncertainty surrounding individual estimates, we can be confident about the order of magnitude of the yearly marginal "cost of illness" due to PM2.5, PM10 and ozone (a few dozens of millions EUR per 10µg/m³). If we also take into account the "subjective" health costs, our estimates run in the billion EUR.

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1 Scope of the study

In 2007-2008, ARCADIS has conducted a study on behalf of the Flemish government, with as main objectives a review and a critical analysis of the existing calculations of environmental health costs in Flanders.

This study covers the effects on human health of air pollution due to particulates (PM2.5 and PM10) and tropospheric ozone[5].

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[4] Metroeconomica.

The approach for the quantification of the costs of the environmental effects follows the approach chosen in the ExternE projects[6]. ExternE follows the Impact Pathway Approach, which consists of the following steps:

- Emissions inventory;
- Dispersion modelling;
- Exposure to concentration;
- Quantification of physical impacts (based upon the concentration-response functions (CRF));
- Monetary valuation of these physical impacts.

As existing approaches in Flanders use ambient concentrations, it is not relevant to undertake a critical analysis of emissions and dispersion modelling (step 1 and 2 in the impact pathway). These steps have therefore not further been considered in this work.

This paper is structured as follows.

In Section 2, we explain how the relationship between exposure to certain pollutants and certain health effects is described at the hand of impact functions. We also give a concise overview of the statistical methods used to estimate these functions.

In Section 3, we give an overview of the methods used to value health effects. We explain why an economic analysis of health outcomes should not limit itself to estimates of the cost-of-illness (the out-of-pocket expenses due to illness on the one hand and the lost productivity on the other hand), but should also consider the willingness-to-pay (WTP) to avoid the pain and suffering caused by illness and premature death. Estimating this WTP requires the use of non-market valuation techniques.

For the purposes of this study, we have limited ourselves to those health effects for which ExternE has published a so-called concentration-response function (CRF) linking ambient concentrations and health end-points. Section 4 reviews these CRFs.

Based upon these CRF, it is possible to make an inventory of the data that are needed to apply these CRFs to a Flemish context. Section 5 provides an overview of the data we have used for this purpose.

In Section 6, we apply the data identified in Section 5 to the CRF reported in Section 4, and obtain an estimate of the health costs in Flanders that can be attributed to PM2.5, PM10 and ozone. We consider both the cost-of-illness and the “subjective” cost of the pain and suffering.

In Section 7, we conclude and formulate policy recommendations. We especially emphasize the needs for further research.

As this paper is based upon a report that exceeds the 200 pages, it is clearly not possible to provide a detailed description of all steps that were undertaken during the project. The emphasis lies on definitions, methodology and policy conclusions.

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[5] Initially, the effects of NO2 were also included in the scope of the study. However, as NO2 and PM correlate highly as indicators of the general quality of the ambient air, it has been decided to drop NO2 from the analysis in order to avoid double counting. PM is considered to be a more appropriate index of general air quality.

[6] ExternE is a research project funded by the European Commission (DG Research) with as main objective to estimate the external costs of energy – see http://www.externe.info/ .

2 Impact functions

Impact functions are necessary in step 4 of the impact pathway: they describe the relationship between exposure to pollutants and certain health effects.

The quantification of health effects is usually expressed as the linking of two components (Hurley et al. (2005), p. 28):

- A **concentration-response** (C-R) **function**, typically giving the *rate of change* in health endpoint, *per unit* change in pollutant ;
- **Background rates** (incidence, prevalence) of health effect in the target population, where:

  Incidence refers to the number of new cases developing a specified condition, within a given population and time period;

  The **prevalence** of a disease is the total number of cases of the disease in the population at a given time.

Linking these together, one can derive an **impact function**, as the number of attributable cases, per year, per unit population (e.g. per 100,000 people at risk), per unit exposure (e.g. per 10µg/m3).

As explained in ExternE (2005, section 6.2)' the **dose-response function** (DRF) relates the quantity of a pollutant that affects a receptor (e.g. population) to the physical impact on this receptor (e.g. incremental number of hospitalisations). In the case of classical air pollutants (NOx, SO2, O3, and particulates), the term dose-response function is formulated directly in terms of the concentration of a pollutant in the ambient air, accounting implicitly for the absorption of the pollutant from the air into the body. Often, the terms **exposure-response function** (ERF) or **concentration-response function** (CRF) are used.

The CRFs for health impacts are often derived from epidemiological studies or from laboratory experiments with animals.

As explained in Hurley et al. (2005, p. 19) one must distinguish between studies measuring **acute effects** and studies measuring **chronic effects**:

- Most studies examine the effects of acute exposure; i.e. the ways that air pollution on a given day or adjacent days affects the health of people on the same day or on the days immediately following;
- Other studies examine the relationships between health and long-term (i.e. chronic, possibly lifetime) exposure, and so the associated impacts are often known summarily as “chronic effects”. The effects of long-term exposure encapsulate the effects of daily variations in air pollution that comprise acute exposure, but they also include aspects which are not captured by (i.e. are more than the aggregate of) the effects of daily variations.

The health effects associated with acute exposure to air pollution are often known as “acute health effects”, even though, strictly speaking, it is the exposure, not the effects, that is acute. For the sake of brevity, we shall, in what follows, refer to “acute” and “chronic” effects.

In the ExternE methodology, it is assumed that the DRF for health impacts are linear, without threshold *at the population level* (even though thresholds can exist at the level of individuals or within homogeneous populations). This assumption makes it possible to characterise a CRF with its slope only.

Two types of regressions techniques are usually used to derive CRF. We will briefly discuss the analytical background and give a concrete example of a health point that is used in this study.

2.1 Poisson regression

As explained in Hurley et al. (2005, p. 28), Poisson regression is used for time series studies:

- where the outcome variable is the daily number of events,
- where the underlying population being studied is very large, and
- where the probability of an adverse event in any one individual is very small.

Typical examples are deaths and hospital admissions.

It is then assumed that the health impact *Y* follows a Poisson distribution, whose expected value is predicted by an explanatory variable *X*. This health effect is usually measured on a logarithmic scale.

Formally:

$$\log(E(Y)) = a + bX.$$

The regression coefficients can then be interpreted as percentage changes: $\frac{d\log(E(Y))}{dX} = \frac{1}{E(Y)}\frac{dE(Y)}{dX} = b$.

For discrete values, we obtain: $\Delta E(Y) = b.E(Y).\Delta(X)$ and thus (for $\Delta(x) = 1$): $E(Y(X + \Delta X)) = (1 + b).E(Y)$.

1 + b is defined as the *relative risk* (RR).

The impact function can then be calculated if one has data with respect to the background incidence E(Y) of the health effect under consideration.

As an example, let us take the morbidity effects attributed to PM2.5 in ExternE. We consider three possible end points: restricted activity days (RAD), work loss days (WLD) and minor restricted activity days (MRAD).

The explanatory variable is the average value of the last two weeks.

We report the estimates value of the slop of the CRF, but also the lower bound (LB) and the upper bound (UB) of the 95% confidence interval.

Table 1 CRF for ill health days attributable to 10 µg/m^3 PM2.5

Effect	Population	slope	LB slope	UB slope
RAD	Adults 15-64 jaar	0.0475	0.0417	5.33
WLD	Adults 15-64 jaar	0.046	0.039	0.053
MRAD	Adults 18-64 jaar	0.074	0.06	0.088

Thus, an increase of the PM2.5 concentration with 10 µg/m^3 per year leads to (within the relevant age category) an increase

- Of the number of RAD with 4.75%.
- Of the number of WLD with 4.6%
- Of the number of MRAD with 7.4%

We have then combined estimates of absenteeism in Flanders (see Section 5.4) with the above CRF to obtain a Flemish gender and age specific impact function for WLD – see Table 2. Similar results have been obtained for the other end points.

Table 2 Flemish impact functions for absenteeism (in days) attributable to PM2.5

Population	slope	LB slope	UB slope
Men (15 to 24)	33 220	28 165	38 276
Men (25 to 49)	245 992	208 558	283 425
Men (50+)	69 728	59 117	80 339
Women (15 to 24)	26 369	22 356	30 382
Women (25 to 49)	217 720	184 589	250 851
Women (50+)	39 582	33 559	45 605
Total	632 611	536 344	728 878

2.2 Logistic regression

As explained in Hurley et al. (2005, p. 28), logistic regression is used when the outcome variable is binary, and the probability *p* of occurrence is approximated by the long run relative frequency of occurrences in the long run - this can arise in studying chronic disease (e.g. chronic bronchitis) or in panel studies of respiratory symptoms or medication usage.

The dependent variable is then the logarithm of the "odds" (where the odds are defined as the ratio between the probability *p* that an effect occurs and the probability *1-p* that it does not occur: $o = \frac{p}{1-p}$).

Formally:

$$\ln(o) = \alpha + \beta X$$

The coefficients of the logistic regression give the percentage change in the odds when the value of the pollutant changes:

$$\frac{d\ln(0)}{dX} = \frac{1}{o}\frac{do}{dX} = \beta .$$

For discrete changes, we obtain: $\Delta o = \beta.o.\Delta x$, or (with $\Delta(x) = 1$): $o(x + \Delta x) = (1 + \beta)o(x)$.

$1 + \beta$ are the "relative odds" (or "odds ratio").

We can also express this in probability terms $p(x + \Delta x) = \frac{o(x + \Delta x)}{1 + o(x + \Delta x)}$.

The increase in the number of days per year where a given effect (per person in the relevant population) is observed is then: $365.(p(x + \Delta(x)) - p(x))$.

The derivation of the impact function requires knowledge of the background odds.

If *p* is very small, then $o \approx p$. It is then possible to interpret relative "odds" as if they were relative probabilities:

$$\frac{d\ln(p)}{dX} = \frac{1}{p}\frac{dp}{dX} \approx \beta .$$

For discrete changes, this gives: $\Delta p \approx \beta . p\Delta x$, or (with $\Delta(x) = 1$): $p(x + \Delta x) \approx (1 + \beta) p(x).$

The increase in the number of days per year during which one measures a given effect (per person in the relevant population) is then: $365.(p(x + \Delta(x)) - p(x)) \approx 365\beta . p(x).$

As an example, we consider the impact of PM10 on bronchodilator use by people who already suffer from asthma. Incidence is measured as the probability that an individual uses a bronchodilator on a given day (Hurley et al. (2005), p.95).

Table 3: CRF for bronchodilator use attributable to PM10

Effect	Population	Percentage total population	Odds ratio	Odds ratio LB	Odds ratio UB
Change in the number of days with bronchodilator use	Children 5-14 year	25	1.005	0.981	1.029
Change in the number of days with bronchodilator use	Adults > 20 years	4.5	1.01	0.99	1.031

In the original study, the probability of the event was 10% and the "background odds" was 0.11. The "small probability approximation" described above is then acceptable. An increase of the PM10 concentration with 10 µg/m^3 leads to an increase of the probability of bronchodilator use by an asthmatic child (adult) with 0.5% (1%) per day.

To give another example, the table below gives the effect of PM10 on lower respiratory diseases. Incidence is measured as the number of symptom days per year.

Table 4 for lower respiratory diseases attributable to PM10

Effect	Population	odds ratio	LB odds ratio	UB odds ratio
Increase in the number of symptom days per adult	Adults with chronic respiratory problems (30% of the adult population)	1 .017	1 .002	1 .032
Increase in the number of symptom days per child	Children 5-14 years	1 .04	1 .02	1 .06

In the original study, the background incidence was 30% (15%) and the corresponding "background odds" were 0.43 (0.18) for children and adults, respectively.

An increase of the concentration of PM10 with 10 µg/m^3 per year leads to an increase in the odds of a symptom day with 1.7% (4%) respectively– this corresponds to odds of 0.373 for children and 0.872 for adults. The probability of symtoms occurring are then 30.43% (15.79%) for children and adults respectively.

2.3 Proportional hazard modelling

Some CRF we have used are based upon “proportional hazard modelling”.

Proportional hazards models are a sub-class of “survival models” in statistics. Survival models consist of two parts: the underlying hazard function, describing how hazard (risk) changes over time at baseline levels of covariates; and the effect parameters, describing how the hazard varies in response to explanatory covariates. The proportional hazards assumption is the assumption that covariates multiply hazard. For instance, if exposure to a pollutant doubles the risk at time 0, the risk also doubles at time *t*, for any *t*.

These models can be approximated with Poisson models[7].

The following CRF for chronic mortality due to PM2.5 has estimated using “proportional hazard modelling”.

Table 5. CRF for chronic mortality due to PM2.5

Pollutant	Effect	RR	LB 95% BI	UB 95% BI
PM2.5	“mortality hazard” per 10 μg/m^3	1.05	NA	NA

This CRF has been calculated for a one-year long, not-recurring reduction in exposure. It is assumed that this reduction affects mortality risks during 10 years (Hurley et al., p 37).

Hurley et al. have shown that this CRF implies that a reduction of PM2.5 concentrations by 10 μg/m^3 during one year leads to an increase in life expectancy of 651 years per 100.000 persons.

3 Economic valuation of health effects

Different perspectives can be taken when calculating the costs of illness and premature mortality. As usual in economic analysis, we will take the perspective of society in its totality.

As argued in Choi and Pak (2002), this perspective has several characteristics.

- Costs incurred by all sectors of society are included: individuals, employers, governments, the health care system, private health insurers, or shared arrangements between any of these sectors.
- These costs also include the loss of forgone productivity (i.e., earnings) due to illness and injury or premature death but also a value associated with the forfeiture of an individual's healthy time.
- The costs do not include transfer payments between parties within the society, such as social welfare payments, because these transfer payments only shift the burden from the individual to society and do not change the society's total resources.
- Costs of administering transfer payments attributable to illness are included, because these administrative costs would not have been consumed in the absence of illness.

As explained in Tarricone (2006), the economic costs of illness can be classified in three categories:

- **Direct costs** refer to *healthcare* and *non healthcare* costs. The first have been defined as the medical care expenditures for diagnosis, treatment, continuing care, rehabilitation, and terminal care, while the second relate to the consumption of non healthcare resources, such as

[7] http://en.wikipedia.org/wiki/Proportional_hazards_model

transportation to and from health providers, certain household expenditures, costs of relocating and certain property losses, legal and court costs, and informal care, that is the time family members or volunteers spend caring for the patient.

- **Indirect costs** refer to productivity losses related to illness or death.
- **Intangible costs** refer to patients' psychological pain and discomfort.

Direct and indirect costs can, at least in principle, be estimated using accounting data.

In order to estimate intangible costs, non-market valuation techniques need to be used. The following methods are usually used to estimate these cost:

- **Revealed preference** methods:

  Hedonic pricing: The basic premise of the hedonic pricing method is that the price of a marketed good is related to its characteristics (including the environmental quality of its surroundings), or the services it provides. The "property value method" assumes that the price of a house is affected by the quality of the local environment, while the "compensating wage" method assumes that differences in risks between different occupations will be reflected in differences in wages. The "compensating wage" method is often used to estimate the value of a statistical life.

  The *avertive behaviour* approach examines the actual voluntary expenditures made by households on items (such as air conditioning) that reduce the impact of environmental end points, or examines the costs associated with any avertive behaviour aimed at reducing risks;

- **Stated preference methods**: these methods directly elicit individuals' Willingness to Pay for a change in an environmental end point (Contingent Valuation (CV)).

The advantages and drawbacks of these methods have been discussed at length in the literature (see for instance Freeman (2003)) – our full report contains an extensive review of recent CV studies.

In order to circumvent the problems with non-market valuation, the so-called **cost of illness approach (COI)** limits itself to an estimation of the direct and indirect cost of illness. The cost of illness is sometimes reported as giving a "lower bound" to the total welfare cost of illness, because it does not incorporate the suffering linked to illness and premature death. However, the actual relationship between the COI and the total welfare cost is more complex:

- The COI depend on the organisation of the health care systems within individual countries (including a possible irrational allocation of resources);
- Early deaths lead to a loss in productive activities, but also to a reduction in health care costs;
- The COI has no welfare-economic meaning, as it reduces the value of people to their productive activities and are independent of the value they attach to their own life.

Other issues are:

- The absence of readily available data on medical costs for a particular type of illness (although databases, such as those available from the WHO, may help to address this problem);
- The estimation of resource costs associated with fatal illnesses, in particular establishing the boundaries between fatal and non-fatal cases in terms of hospital treatment costs;
- The problems associated with predicting how many currently non-fatal cases may result in deaths in the future (in order to avoid double-counting).

Another specific issue in the valuation of health effects is the approach to take when valuating the cost of premature death. Basically two approaches are possible:

- **Value of statistical life**. This can best be explained at the hand of an example. Take a group of 10,000 people, each of whom has a probability of 0.0004 of dying next year. Suppose that a pollution control policy would reduce that probability to 0.0003, a change of 1 in 10,000. If each individual in the group is willing to pay 800 EUR for this policy, the total willingness to pay of the group is 8 million EUR. If the policy is adopted, on average, one person less will die per year. The value of a statistical life (**VSL**) in this group is then 8 million EUR.
- Alternatively, one can use the **Value of a Life Year Lost (VOLY)**. The main advantage of the VOLY concept is that the VSL does not take into account how many expected life years are lost whenever a premature death occurs.

The preferred paradigm of deriving WTP values for health risk reductions from the willingness of individuals to pay for risk reductions that affect themselves clearly present difficulties in the case of children, as children have neither the maturity nor the financial resources to clearly define their willingness-to-pay. Therefore, an alternative perspective has to be adopted from which to estimate child health values.

There are three potential perspectives from which preferences for children's health risks might be elicited:

- that of society (parents and non-parents),
- that of adults placing themselves in the position of children, and
- that of parents assessing risks faced by their own children

There is a series of methodological issues that make transfer of values from adults to children difficult – we refer to the complete report for more details.

A number of studies have examined possible differences of values between adults and children, but their findings have been mixed. In the context of this paper, the most important finding is that parents are more willing to pay to reduce their children's health risks than their own. The estimated marginal rate of substitution (MRS) is generally greater than one, and is, on average close to 2.

4 Concentration- response functions

For the purposes of this study, we have limited ourselves to those health effects for which ExternE has published a CRF. In the case of particulates, we have considered the effect on premature deaths (both due to chronic and to acute exposure), on new cases of chronic bronchitis, on hospital admissions because of respiratory or heart problems, on consultations with primary care physicians for asthma or respiratory problems, on absenteeism and (in more general terms) the activity levels, on the use of bronchodilators and on the number of symptom days. In the case of ozone, we consider premature deaths (due to acute exposure), hospital admissions because of respiratory problems, consultations with primary care physicians for allergic rhinitis, reduced activity levels, bronchodilator use and symptom days.

Several of these health end points are described in the "International Classification of Diseases" (ICD)[8]. The following table gives the correspondence between the "verbal" description of a health endpoint and the ICD:

[8] http://www.who.int/classifications/icd/en/index.html

Health end point	ICD
Respiratory problems	460-519
Heart problems	390-429
Allergic rhinitis	477
Upper respiratory problems (with the exception of allergic rhinitis)	460-3; 465; 470-5 en 478
Lower respiratory problems	464, 466, 476, 480-3, 485-7, 490-2, 494-6, 500, 501, 503-5, 510-5, 518, 519, 786

We list here the CRF we have used, with some clarifications where needed.

4.1 Mortality

The only CRF covering mortality due to chronic exposure has already been discussed in Section 2.3. From this CRF, it follows that if PM2.5 concentrations decrease with 10 µg/m^3 during one year, this leads to an expected gain of 651 year per 100 000 people.

With respect to mortality due to acute exposure, three CRFs are used:

Table 6. CRF for acute mortality due to PM10 and ozone

Effect	Slope	LB slope	UB slope
% change in mortality in the adult population per 10 µg PM10/m^3	0.006	NA	NA
% change in mortality in the adult population per 10 µg ozone/m^3	0.003	0.001	0.0043
% change in infant mortality per 10 µg PM10/m^3	0.04	0.02	0.07

ExternE assumes that 6 months of life are lost per premature death.

4.2 Morbidity linked to PM10

The following effects have been considered:

- New cases of chronic bronchitis
- Hospital admissions for respiratory or heart problems
- Primary care consultations for asthma and upper respiratory problems (with the exceptions of allergic rhinitis).

The exact CRFs are reported in the tables below.

Table 7. CRF for new cases of chronic bronchitis

Population	Slope	LB slope	UB slope
Adults > 27 years	0 .07	-0 .005	0 .143

Note the slope of this CRF is not statistically significant. Moreover, these results are based upon one single study in a population with very specific behavioural patterns (7th Day Adventists in California).

Table 8 CRF for hospital admissions attributed to PM10.

ICD	Slope	LB slope	UB slope
460-519	0 .0114	0 .0062	0 .0167
390-429	0 .006	0 .003	0 .009

Table 9 CRF for primary care consultations attributed to PM10

Health end point	Population (age)	Slope	LB slope	UB slope
Astma	0-14	0 .025	0 .000	0 .052
Astma	15-64	0 .031	0 .012	0 .050
Astma	65+	0 .063	0 .021	0 .112
ICD 460-3; 465; 470-5 en 478	0-14	0 .007	-0 .001	0 .014
ICD 460-3; 465; 470-5 en 478	15-64	0 .018	0 .009	0 .028
ICD 460-3; 465; 470-5 en 478	65+	0 .033	0 .017	0 .050

Note that the CRF for upper respiratory problems is not significant for the age category 0-14.

The CRF for bronchodilator use and for lower respiratory problems attributed to PM10 have already been discussed in Section 2.2.

4.3 Morbidity linked to PM2.5

The CRF for health end points attributed to PM2.5 have already been discussed in Section 2.2.

4.4 Morbidity linked to ozone

The following effects have been considered:

- hospital admissions due to respiratory problems amongst people aged 65+
- minor restricted activity days (MRAD)
- number of cough days (for children)
- number of days with lower respiratory problems (except cough) (for children)
- primary care consultations for allergic rhinitis
- bronchodilator use by children with asthma
- bronchodilator use by adults with asthma

The exact CRFs are reported in the tables below.

Table 10. CRF for hospital admissions due to respiratory problems amongst people aged 65+ attributed to ozone.

Population	slope	LW slope	UB slope
Adults aged 65+	0 .005	-0 .002	0 .012

Note that this effect is not statistically significant.

Table 11. CRF for MRAD attributed to ozone

Population	slope	LW slope	UB slope
Adults 18-64 years	0 .0148	0 .0057	0 .0238

The following CRF have been calculated for children aged 5-14 year from the *general* population.

Table 12 CRF for symptom days amongst children attributed to ozone.

Effect[9]	Odds ratio	OG odds ratio	BG odds ratio
Change in the number of cough days	1 .05	0 .99	1 .12
Change in the number of days with lower respiratory problems (except cough)	1 .03	0 .92	1 .15

The incidence rates were 5.4 % and 1 .5%, respectively. This implies that the background probability is a good approximation of the "background odds" (see section 2.2).

Thus, an increase in ozone concentration with 10 µg/m^3 per year leads to (in the population 5-14 years):

- An increase in the number of cough days with 5%
- An increase in the number of days with lower respiratory problems (except cough) with 3%

In the next CRF, the independent variable is the average concentration of the 4 past days. Because these results are based uniquely on studies in London, it is unclear to what extent the results can be extrapolated to Europe.

Table 13 CRF for primary care consultations for allergic rhinitis attributed to ozone.

Population	Slope	LB slope	UB slope
Children 0-14	0.082	0 .051	0 .116
Adults 15-64	0 .055	0 .042	0 .07

The next CRF and incidences have been estimated for children with asthma during "risk days".

Table 14 CRF for bronchodilator use by children with asthma (attributed to ozone).

Effect	Population	Odds ratio	LB odds ratio	UB odds ratio
Change in the probability of bronchodilator use during a risk day	Children 5-14 year with asthma	1 .41	1 .05	1 .89

In the original study, the background probability of bronchodilator use during a "risk day" was 40% – this corresponds to a "background odds" of 0.66 (see Section 2.2). Thus, an increase in the ozone

[9] This effect is not statistically significant.

concentration with 10 µg/m^3 per year leads to an increase in the odds of bronchodilator use by an asthmatic child with 41% per risk day. If we use the "background odds" of the original study, we obtain that the odds increase to 0.94, which corresponds to a probability of 48.5%. Thus, the probability of bronchodilator use increases with 21%.

It is not clear to what extent this result is representative. The original study was limited to a single location. The relation between bronchodilator use and ozone was only established for days where the children did *not* use corticosteroids. The observation period was limited from the beginning of April to the end of June. Finally, the calculation of the impact function in ExternE is based upon very specific assumptions – we refer to the full report for more details.

The next CRF is based upon a sample of 75 adults older than 20 with asthma or COPD.

Table 15. Impact of ozone on bronchodilator use by adults

odds ratio	OG odds ratio	BG odds ratio	Measured incidence in the summer	Background odds in de zomer
1 .009	0 .997	1 .02	0 .32	0 .47058824

In the original study, a background incidence of 32% was observed, which corresponds to "background odds" of 0.4706 (see Section 2.2).

Following the same calculations as above, it can be shown that an increase in ozone concentrations with 10 µg/m^3 per year leads to an increase in the probability of bronchodilator use with 0.6%. This relationship is not statistically significant.

5 Data used

5.1.1 Data needs for an application to Flanders

For each of the effects described in Section 4, we have sought data on:

- Incidence or prevalence rates (which are required to construct region-, gender- and age-specific impact functions);
- The cost-of-illness: treatment costs on the one hand, lost productivity on the other hand;
- The willingness-to-pay to reduce the pain and suffering related to illness and premature deaths.

5.2 Data on incidence and prevalence rates

For each health end point covered in this study, we need three types of data:

- Data on hospital admissions due to this end point;
- Data on the number of primary care consultations due to this end point;
- Data on medication use due to this end point.

We first verify the availability of date on hospital admissions.

Data on emergency hospital admissions due to heart and respiratory problems have been obtained from the RCM-MKG[10] database. This database registers the clinical data related to all admissions in non-psychiatric hospitals in *Belgium*.

Table 16: Yearly number of emergency hospital admissions per 100 000 individuals in the Flemish Region

Year	2001	2002	2003	2004	2005
Respiratory problems	860	879	855	747	892
Heart problems	759	746	733	721	738

The figures for hospital admissions due to respiratory problems are significantly higher than the figures used in CAFE[11]: 617 per 100 000 for all ages (Hurley et al. pp 78-79), while the figures for heart problems are quite close to the figures used in CAFE: 723 per 100 000 (Hurley et al. p 78-79).

The most important limitations of these data are:

- It is possible to disaggregate these data up to the level of the "arrondissement" (in Belgium, this is the level of government grouping several municipalities). However, because individuals are not always admitted in hospitals within the "arrondissement" where they live, we have not sought a geographical differentiation of the date below the level of the Flemish Region.
- Some people living in Flanders are admitted in hospitals in Wallonia or in Brussels (and vice versa). It is not possible to correct the data for this.
- It is not clear to what extent the definition of "emergency hospital admissions due to heart and respiratory problems" used in the RCM-MKG database corresponds to the effects that were measured in the epidemiological studies that have lead to the estimates of the CRFs we have used here.
- The RCM-MKG only registers the primary reason for the hospital admissions. Secondary diagnoses are not reported.

However, the RCM-MKG data are still the best data that are currently available for the purposes of this project.

Data on all other medical end points studied here are extremely scarce. For instance:

- The reasons for consulting with primary care physicians are not routinely reported.
- There are no centralised data on the sales of non-prescription drugs.
- There are no structural data on the prevalence of asthma and chronic bronchitis in Belgium.

Hence, we had to rely on indirect estimates.

Our mean source of information has been the *Intermutualistisch Agentschap* (IMA)[12]. The databank of IMA covers all Belgian residents. We have proceeded as follows:

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[10] Résumé Clinique Minimum- Minimale Klinische Gegevens.

[11] CAFÉ stands for Clean Air for Europe, the European Union's thematic strategy for air quality.

[12] In Belgium, health insurance is mandatory. All residents have to choose an affiliation with a recognized mutual health insurance provider ("mutualiteit"). These providers reimburse (partially) all medical expenses recognized by the Government, and are funded by, on the one hand, employers' and employees' contributions

- For all health end points covered by this study, we have asked two medical experts[13] to identify medication[14] that is typically used by chronic patients suffering from this affliction;
- IMA has compared this list with drug prescriptions at the individual level to identify chronic patients for each illness[15].
- For each illness, the number of primary care consultations *due to the illness* is assumed to be equal to the difference between the average number of primary care consultations by identified patients, and the average number of primary care consultations by the general population.

We illustrate this approach with our estimates of primary care consultations related to asthma.

In the case of asthma, patients have been identified at the hand of their use of anti-inflammatory drugs. IMA has used drug prescriptions to provide the following estimate of the Flemish population of asthma patients:

Table 17 : Flemish asthma population in 2006

Age	total population	asthma population
0-14	986 640	111 880
15-64	3 988 880	140 160
65+	1 085 240	102 .400

In order to verify their validity, we have compared these estimates with the estimates from the Belgian Health Survey[16]:

Table 18 Asthma prevalence Belgian Health Survey versus IMA

	Belgian Health Survey (2004)	IMA estimate
Children (0-14)	4.4%	11%
Men (15-54)	2.3%	3.5%
Women (15-54)	2.6%	3.5%
men (65+)	5.9%	9.4%

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to social security and on the other hand, by the federal government. The IMA is an association that groups all the recognized mutual health insurance providers.

[13] Professor Nemery (Univeristy of Leuven) and Professor Desager (University of Antwerp).

[14] Characterised by the ATC Code, where ATC stands for Anatomical Therapeutic Chemical Classification System. The ATC is a classification system managed by the World Health Organisation, and classifies drugs, on the one hand according to the organs or systems they affect, and on the other hand according to their therapeutical and chemical properties.

[15] For obvious privacy reasons, these data have not been communicated to us.

[16] http://www.iph.fgov.be/EPIDEMIO/EPINL/crospnl/hisnl/his04nl/his22nl.pdf

Women (65+)	5.3%	9.4%

The IMA estimates are higher than the estimates of the Health Survey. These differences can be explained as follows:

- The Health Survey is based upon direct questioning. It is possible that parents are reluctant to admit that their child is asthmatic.
- The drugs for the treatment of asthma and Chronic Obstructive Pulmonary Disease (COPD) are often the same. In the age category 65+, a large proportion of patients using anti-inflammatory drugs are likely to suffer from COPD rather than from asthma.
- A crucial parameter in the approach we have used is the threshold of annual drug use above which a patient can be considered to be chronic. If physicians are too eager to prescribe some types of drugs, this can lead to an overestimation of the number of chronic patients.

As a next step, IMA has calculated the number of primary care consultations, both for the general population and for asthma patients. The difference between the two figures is entirely attributed to asthma.

Table 19: Primary care consultations

	Primary care consultation of total population	Primary care consultations of asthma patients	Primary care consultations attributed to asthma
0-14 jaar	2 .23	4 .2	1 .97
15-64 jaar	3 .44	7 .63	4 .19
65+ jaar	9 .27	14 .98	5 .71

A similar procedure has been used:

- to identify the people with upper respiratory problems,
- to estimate the number of primary care consultations due to upper respiratory problems,
- to estimate the number of days of bronchodilator use by asthma patients,
- to identify people with allergic rhinitis and
- to estimate the number of primary care consultations due to allergic rhinitis.

We refer to the complete report for more details.

Due to a lack of data, it has not been possible to apply this procedure to identify people with lower respiratory problems, to estimate the number of primary care consultations due to lower respiratory problems or to estimate the number of cough days. In these cases we have maintained the incidence or prevalence rates as reported in ExternE.

Finally, there is a lack of reliable data on the number of new cases of chronic bronchitis. This health effect has therefore been dropped from the analysis.

5.3 Treatment costs

The RCM-MKG database is linked with a database containing the corresponding financial data, *including the invoices*. Thanks to this link, it is possible, in principle, to calculate the actual cost of any hospital admission. However, due to limitations imposed by privacy legislation, we have not been allowed to access these linked data to estimate the unit cost of emergency hospital

admissions due to heart and respiratory problems. Instead, we have relied upon the cost estimates per Major Diagnostic Category (MDC) – this system classifies all major diagnoses in 25 mutually exclusive categories. An average treatment cost for each MDC is available from the Belgian Federal Health Ministry[17]. Clearly, such an "average" cost can only be a very gross approximation to the real cost.

For the health effects that concern us, the average cost per hospital stay is[18]:

Table 20. Average cost price of a hospital stay

MDC	Average cost in EUR (2008)
Respiratory system	4,599.99
Cardiovascular	5,246.77

These figures have to be interpreted with great care, as there is no perfect correspondence between the MDC and the ICD used in ExternE. We are not aware of any information that could be used for a more detailed classification, or for an assessment of the margins of uncertainty.

The unit costs of primary care consultations (21.53 EUR) have been obtained from IMA.

In order to estimate the cost of bronchodilator use by asthma patients, we have assumed that Ventolin is representative. Its unit price is 4.99 EUR and it can be used for 25 daily doses.

5.4 Productivity losses

As noted above, there are three dimensions to productivity losses:

- The loss of productivity on the regular labour market due to illness;
- The lost household work due to illness and the informal care provided by relatives and friends;
- The lost productivity due to premature death.

In order to estimate the productivity losses on the regular labour market due to illness, we have used the periodic SDWorx survey on absenteeism. We have extrapolated the SDWorx sample to Flanders to obtain an estimate of the total cost of absenteeism in Flanders in 2007. The main limitations of our estimates are:

- They only cover companies based in Flanders. These figures do not take into account the absenteeism of people who live in Flanders, but who work in Wallonia or in Brussels. Conversely, this table does include the absenteeism of people living in Wallonia or in Brussels, but who work in Flanders.
- The SDWorx estimates only cover employees, not independent workers.

Table 21 Absenteeism in Flanders based upon SDWorx study

	Age	Number of people	Cost of illness	Number of sick days	Sick days per capita	Cost per day of illness
Men	15 -24	17.964	10.222.113	100.921	6	101

[17] https://tct.fgov.be/etct/anonymous?lang=nl

[18] https://tct.fgov.be/etct/anonymous?lang=nl , Tabel 4.

	25 - 49	143.170	98.131.651	754.374	5	130
	50+	35.193	25.171.687	172.464	5	146
	15 -24	14.553	6.689.648	78.953	5	85
	25 - 49	99.566	66.099.882	571.766	6	116
Women	50+	17.175	9.908.421	83.185	5	119
Total		327.621	216.223.402	1.761.662	5	123

It is noteworthy that the average number of sick days according to this estimate is somewhat lower than the estimate used in ExternE (7.2 days per person).

In order to estimate the unit cost of lost household work, we have used the average value of "PWA cheques"[19] (6.20 EUR per hour) as a lower bound. Due to a lack of reliable data with respect the unit cost of child care, we have not been able to assess the extra cost of paid child care due to illness. In order to assess the amounts of household work that is indeed lost, we have used the work by Glorieux et al. to estimate that an adult Flemish person spends 2.69 hours on household work per day.

We have not considered the value of the informal work provided by relatives and family, for the following reasons:

- It is very difficult to estimate the actual time invested in informal care, because this care takes place in parallel with normal household work.
- It is not clear what unit cost should be attributed to this work if it does not come at the expense of work on the paid labour market.

Finally, we have assumed that premature deaths due to pollution by PM and ozone do not lead to any productivity losses in Flanders. This is justified because, on average, the years of live lost occur after the legal retirement age. Some studies have indicated that particulate pollution can lead to increased infant mortality, but there are legitimate reasons to doubt that these children would have reached the adult age anyway.

5.5 WTP values

On top of our estimates of the Cost-of-Illness, we have derived values relating to the non-market element of the willingness to pay i.e. WTP to avoid pain and suffering.

To do so, we have explored the potential for reliably transferring values from appropriate existing studies, undertaken elsewhere, for use in the Flemish policy context.

Value transfer increases the uncertainty in the estimated value since the time and/or place of the original study (the study site) will be different from the new decision making context. Thus, a crucial question becomes: What level of (in)accuracy is acceptable in cost-benefit analysis? Results from validity tests of value transfer procedures have shown that the uncertainty in spatial and temporal benefit transfer can be quite large.

[19] PWA cheques are a payment instrument for services delivered by employees of PWAs (Plaatselijk Werkgelegenheidsagentschap of Local Employment Agency) – typically, these are people that have dropped out of the regular labour market, and who perform manual household tasks.

There are two main approaches to benefit transfer: Unit Value Transfer with, and without, income adjustments; Function Transfer including Meta analysis.

5.5.1 Unit value transfer

Simple unit transfer is the easiest approach to transferring value estimates from one site to another. This approach assumes that the well-being experienced by an average individual at the study site is the same as will be experienced by the average individual at the policy site.

The simple unit value transfer approach may not be appropriate where transfer between countries with different income levels and costs of living is intended. Instead, unit transfer with income adjustments may be applied.

The adjusted benefit estimate B_p' at the policy site can be calculated as

$$B_p^{'} = B_S\left(\frac{Y_P}{Y_S}\right)^{\beta}$$

where B_s is the original benefit estimate from the study site, Y_s and Y_p are the income levels at the study and policy site, respectively, and ß is the income elasticity of demand for the environmental good in question. There are, however, little empirical evidence on how the income elasticity of demand ß for different environmental goods and health impacts varies with income.

However, it should be noted that even if adjustment for differences in income and cost of living in different countries are made, these will not account for differences in individual preferences, initial environmental quality, and cultural and institutional conditions between countries (or even within different parts of a country).

5.5.2 Function transfer

With the value (or benefit) function approach, an empirical relationship (function) between WTP and characteristics of the affected population and the resource being assessed is specified. For a stated preference study, the benefit function can be written as:

$$WTP_{ij} = b_0 + b_1 G_j + b_2 H_{ij} + e$$

where WTP_{ij} = the willingness-to-pay of household i at the study site j, G_j = the set of characteristics of the environmental good at site j, and H_{ij} = the set of characteristics of household i at site j, and b_0 , b_1 and b_2 are sets of parameters and e is the random error.

To implement this approach the analyst has to find a study in the existing literature with estimates of the constant b_0 and the sets of parameters, b_1 and b_2. Then the analyst has to collect data on the two groups of independent variables, G and H, at the policy site, insert them in the equation and calculate households´ willingness-to-pay at the policy site.

The main problem with the benefit function approach arises from the possible exclusion of relevant variables in the WTP (or bid) function estimated in a single study.

Transferring the entire value function is conceptually more appealing than just transferring unit values because more information is effectively taken into account in the transfer.

5.5.3 Meta-analysis

Instead of transferring the benefit function from one selected valuation study, results from several valuation studies could be combined in a meta-analysis to estimate one common benefit function. Meta-analysis has been used to synthesize research findings and improve the quality of literature

reviews of valuation studies in order to come up with adjusted unit values. In a meta-analysis, several original studies are analysed as a group, where the result from each study is treated as a single observation in a regression analysis. If multiple results from each study are used, various meta-regression specifications can be used to account for such panel effects. The resulting regression equations explaining variations in unit values can then be used together with data collected on the independent variables in the model that describes the policy site to construct an adjusted unit value. The regression from a meta-analysis would look similar to the equation for function transfer, but with one added independent variable; C_s = characteristics of the study s (and the dependent variable would be WTP_s = mean willingness-to-pay from study s).

5.5.4 Premature mortality

For premature mortality end-points, we have applied the survey data gathered in two recent stated preference research exercises[20] to create value functions in which socio-economic data from Flanders is used to derive WTP values fitted to the Flemish context. This allowed us to explore a value transfer technique additional to relying on simple unit value transfer.

In practice, however, analysis of the NEEDS data has found that the size of the errors associated with value function transfer are greater than those associated with unit value transfer. The statistical robustness of the results is found to be the greatest in the sample size afforded by pooling the data from nine countries covered by the original study. The recommendation is therefore to adopt the unadjusted 9-country pooled results from NEEDS as a low range estimate for the value of a life year (VOLY).

The results from the single country analysis of the NewExt data seem to suffer from low sample sizes; none of the socio-economic variables one might expect to have a significant relationship with WTP were found to be significant. However, the 3-country pooled data analysis generated values of a statistical life (VSL) of the same order as previous analyses (e.g. CAFÉ CBA) and found income, amongst other socio-economic variables, to be significant. We have therefore adopted the results from the pooled value function transfer, using NewExt data, to provide a range for VSL and an upper bound VOLY estimate. The recommended values for mortality end-points are summarised in Table 22.

Table 22. Recommended values for mortality end-points (€m, 2007 prices).

	VSL	**VOLY**	**Derived from:**
Lower value	0.83	0.027	NewExt; NEEDS
Higher value	2.13	0.125	NewExt

5.5.5 Morbidity

Previous analysis on the most comprehensive and recent data collected on the valuation of morbidity end-points (Ready et. al. 2004), had concluded that unit value transfer was likely to be as accurate as function value transfer. We therefore adopted a unit value transfer process for the pain and suffering component of WTP, applying to the results of the pooled sample from the five country

[20] The EC funded projects NEWEXT (Markandya et al. (2004)) and NEEDS (Rabl et al. (2006)). The NewExt results for mortality valuation have been used in the CAFE cost-benefit analysis.

study reported in Ready et. al. The recommended morbidity “pain and suffering” values are therefore those presented in Table 23.

Table 23. Transferred Flemish Pain & Suffering WTP components - Morbidity

Health endpoint	Central unit values (€2007)
Hospital admission	549
ERV for respiratory illness	284
GP visit – asthma	18
GP visit - lower respiratory symptoms	45
Respiratory symptoms in asthmatic adult	163
Respiratory symptoms in asthmatic child	346
Respiratory medication use	1
Restricted activity day (working adult)	58
Restricted activity day (age > 65)	58
Restricted activity day (needs to stay in bed)	58
Restricted activity day (work loss day)	48
Minor restricted activity day	48
Cough day	48
Symptom day	48
Work loss day	48
Minor restricted activity day	48
Chronic bronchitis	234,731

6 Estimate of environmental health costs in Flanders

We have used the data described in Section 5 to estimate total environment related health costs corresponding to changes in the existing ambient concentrations of ozone and PM. The effects have always been calculated for changes of 10 µg/m^3 for each pollutant and per year.

We have considered the following effects:

- Premature mortality
- Morbidity linked to PM10
- Morbidity linked to PM2,5
- Morbidity linked to ozone

The approach always consists in the following steps:

- We start with CRF used in the CAFE and ExternE projects;
- If there are Flemish data on the background rates, we combine them with the CRF to obtain an impact function;
- If there are no Flemish data on the background rates, we use the impact function estimated in ExternE;
- We combine the impact function with the unit cost (COI or WTP) to calculate the annual cost linked to an increase of ambient concentration levels of the pollutant with 10 µg/m^3 .

The costs we consider here are thus marginal costs: they are the costs linked to small changes in the existing concentrations of the pollutants under consideration. Using this method to calculate the total cost of air pollution in Flanders (rather than the marginal cost) is only valid if the estimate of the CRF is also reliable in the (purely hypothetical and unknown) reference point without pollution induced by human activity. We are not aware of any studies indicating that such an extrapolation would be acceptable.

To put the figures below in perspective, note that according to the most recent report of the Flemish Environmental Agency[21], the average annual concentrations of PM lay in the following intervals:

- PM10: between 21 µg/m³ and 38 µg/m³.
- PM2.5: between 17 and 23 µg/m³

For ozone, the 2004 average concentration was 68.5 µg/m³. In 2008, the 8 hours average concentration did not exceed 120 µg/m^3 for more than 28 days.

If possible, we do not only report the central value of each estimate, but also the lower bound (LB) and the upper bound (UB) of the estimated 95% confidence intervals. Wherever we calculate the sum of the effects, we shall assume that these are stochastically independent, and thus that the lower bound (upper bound) of the combined effects can be calculated as the sum of the lower bounds (upper bounds) of the individual effects. Note that this assumption is only introduced because of a lack of data – the estimates need thus to be interpreted with a lot of circumspection.

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[21] VLAAMSE MILIEUMAATSCHAPPIJ (2009), Luchtkwaliteit in het Vlaamse Gewest. Jaarverslag Immissiemeetnetten. Kalenderjaar 2008.

6.1 Mortality effects

In 2005 (most recent data when the study was written[22]) 56 890 people died in Flanders. We will use this as the background rate for the impact function.

The CRF used in CAFÉ has shown that a one-off decrease of ambient PM2,5 concentration with 10 µg/m^3 during one year leads to a gain of 651 expected life years per 100 000 people over a period of 10 year. As Flanders currently has 6 078 600 inhabitants[23], this corresponds to 39 572 life years for Flanders taken in its totality.

Using the VOLY values reported in Table 22, we obtain the following estimate of the cost of chronic mortality due to 10 µg/m^3 PM2.5:

Table 24 Cost of chronic mortality due to 10 µg/m^3 PM2,5 (VOLY measure).

LB VOLY	UB VOLY
1,126 million EUR	5,762 million EUR

If we combine the CRF used in CAFE with Flemish mortality figures, we obtain that an increase of PM10 concentrations with 10 µg/m^3 per year leads to 341 additional premature deaths. Using the VOLY values reported in Table 22, we obtain the following estimate of the cost of acute mortality due to 10 µg/m^3 PM10:

Table 25 Cost of acute mortality due to 10 µg/m^3 PM10 (VSL measure).

LB VSL	UB VSL
330 million EUR	847 million EUR

If we combine the CRF used in CAFE with Flemish mortality figures, we obtain that an increase of ozone concentrations with 10 µg/m^3 per year leads to 171 additional premature deaths. Using the VOLY values reported in Table 22, we obtain the following estimate of the cost of acute mortality due to 10 µg/m^3 ozone:

Table 26 Cost of acute mortality due to 10 µg/m^3 ozone (VSL measure).

	Central value of CRF	LB CRF	UB CRF
Number of premature deaths	170,67	56,89	244,627
Lower estimate VSL	165 000 026	55 000 009	236 500 037
Higher estimate VSL	423 433 801	141 144 600	606 921 782

We see here that the combination of two sources of uncertainty (the uncertainty with respect to the slop of the CRF on the one hand and the uncertainty regarding the unit values of the VSL on the other hand) lead to a very large difference (factor 10) between the lower bound (55 million EUR) and the lower bound (607 million EUR) of the estimate.

[22] http://www.statbel.fgov.be/downloads/deaths_nl.xls

[23] http://www.statbel.fgov.be/verkiezingen2006/downloads/com_gem_02000_nl.pdf

Mortality data for babies have been obtained from the Flemish Health Agency[24]:

Table 27: Postneonatal mortality in Flanders

year	Number of births	Postneonatal deaths per 1000 births	Total postneonatal deaths
2006	66.139	1.5	99.2085

If we combine the CRF used in CAFE with Flemish mortality figures, we obtain the following impact function:

Table 28: Impact function for acute infant mortality due to PM10

	Central value	OG	BG
Effect on number of deaths	3.96834	1.98417	6.944595

In order to calculate the VSL of an infant we use the MRS for an adult VSL as recommended in CAFÉ (see Section 3). This implies that we take a lower value of 874 820 EUR and a higher value of 4 490 040 EUR.

Table 29 Cost of acute infant mortality due to 10 µg/m^3 PM10 (VSL approach)

	Central value	LB	HB
Lower value VSL	3 836 504	1 918 252	6 713 883
Higher value VSL	19 690 974	9 845 487	34 459 205

Again, we see that the combination of two sources of uncertainty leads to a factor 10 difference between the higher and the lower estimate. Notwithstanding these high margins of uncertainty, we see that the cost of infant mortality is relatively low compared to the costs of premature adult mortality. This is uniquely due to the very low background share of post neonatal mortality in total mortality – both the VSL and the slope of the CRF are much higher than the corresponding figures for adults.

6.2 Morbidity linked to PM10

We have combined the CRFs used in CAFE with our estimates of the COI and with the WTP estimates summarized in Table 23 to obtain the following summary of PM10 related health costs in Flanders:

Table 30: Morbidity effects attributed to 10mg/m³ PM 10

Effect	Average	Lower bound	Upper bound
COI			
Emergency hospital admission due to respiratory problems	2 844 239	1 546 867	4 166 560
Emergency hospital admission due to heart problems	1 412 223	706 112	2 118 335

[24] http://www.zorg-en-gezondheid.be/topPage.aspx?id=4828

Primary physician consultation due to asthma	255 997	76 071	440 680
Primary physician consultation due to upper respiratory problems (with the exception of allergic rhinitis)	126 017	64 252	192 711
Bronchodilator use	39 034	-42 876	123 639
Total COI	4 677 510	2 350 425	7 041 925
WTP			
Emergency hospital admission due to respiratory problems	185 084	100 660	271 132
Emergency hospital admission due to heart problems	155 749	77 874	233 623
Primary physician consultation due to asthma	225 581	67 033	388 322
Lower respiratory problems (adults)	94 475 712	11 164 776	177 043 980
Lower respiratory problems (children)	70 743 482	35 477 539	105 799 717
Total WTP	165 785 608	46 887 882	283 736 774
Total COI + WTP	170 463 118	49 238 308	290 778 699

There are two noteworthy observations to make.

First, the willingness to pay to avoid the pain and suffering linked to lower respiratory problems is obviously the most important cost category – it corresponds to 97% of the total cost!

Second, the uncertainty surroundings these estimates is very important, as there is a factor 5 difference between the upper and the lower bound of the confidence intervals. Moreover, these margins are based uniquely on the confidence intervals of the CRF, and do not take into account the numerous other uncertainties.

6.3 Morbidity linked to PM2.5

We have combined the CRFs used in CAFE with our estimates of the COI and with the WTP estimates summarized in Table 23 to obtain the following summary of PM2.5 related health costs in Flanders:

Table 31: Morbidity effects attributed to 10mg/m³ PM2.5

Effect	Average	Lower bound	Upper bound
Productivity loss due to absenteeism	77 660 174	65 842 321	89 478 027
Cost of lost Household work	60 217 281	52 864 434	67 570 128
WTP to avoid days with restricted activity	221 545 670	194 493 777	248 597 562

Total	359 423 125	313 200 533	405 645 717

The cost of morbidity attributed to PM2.5 is thus higher than the cost of morbidity attributed to the same concentration of PM10. In this case as well, the "subjective" health costs are higher than the "real" economic costs due to productivity losses. Finally, the margins of uncertainty are much lower in the case of PM2.5 than in the case of PM10.

6.4 Morbidity linked to ozone

We have combined the CRFs used in CAFE with our estimates of the COI and with the WTP estimates summarized in Table 23 to obtain the following summary of ozone related health costs in Flanders:

Table 32: Morbidity effects attributed to 10mg/m³ ozone

Effect	Average	LB	UB
COI			
Hospital admissions due to respiratory problems amongst 65+	781 641	-312 656	1 875 938
Lost household work	7 731 215	2 977 562	12 432 629
Primary physician consultations due to allergic rhinitis	914 171	691 959	1 169 635
Bronchodilator use by children	60 765	8 457	113 228
Bronchodilator use by adults	34 508	-11 547	76 417
Total COI	9 522 300	3 353 774	15 667 847
WTP			
Hospital admissions due to respiratory problems amongst 65+	50 864	-20 346	122 073
Minor restricted activity days (adults)	23 452 309	9 032 308	37 713 849
Coughing by children	35 546 605	-7 132 368	84 991 448
Other lower respiratory problems (children)	6 182 549	-16 514 034	30 857 229
Total WTP	65 232 327	-14 634 439	153 684 600
Total COI + WTP	74 754 627	-11 280 665	169 352 447

It is clear that the most important cost categories are the willingness to pay to avoid the coughing by children and to reduce the minor restricted activity days for adults. However, there is a large

uncertainty surrounding the estimate for the willingness to pay to reduce coughing by children – it is not even significantly different from zero!

It is also noteworthy that even the lower estimate of the costs of the mortality effects of ozone is twice as high as the central value of the costs of the morbidity effects.

7 Conclusion and policy recommendations

The estimates provided in this study are subject to numerous sources of uncertainty:

- A lot of questions surround the validity of the unit costs used in the study (both the "real" costs of illness as the "subjective" willingness's to pay).
- With the current state of knowledge, it would make little sense to work on more detailed inventories of ambient concentrations or on more refined exposure scenarios. Indeed, the CRFs that are currently used are not differentiated across time and space anyway. Moreover, a lot of uncertainty surrounds the relative magnitude of the variance of exposure across the Flemish territory compared to the variance per grid of 4x4 km. Therefore, only average concentrations can be taken into account.
- The margins of uncertainty surrounding the estimates of the CRFs have been calculated with statistical techniques and are explicit. It is however unknown to what extent the estimated effects are correlated.
- Our estimates of the cost of illness are not based upon actual expenditures. To estimate the cost of hospital admissions, we had to use "standard costs". Our estimates of the prevalence of some chronic afflictions and of primary care consultations are also based upon indirect methods (estimates of the use of prescription drugs).
- In our estimates of the productivity losses, we have not been able to estimate the cost of additional child care or of informal care provided by relatives and friends. We have not taken into account absenteeism of people who reside in Flanders but work in Brussels.
- Value transfer is a helpful tool for generating WTP estimates in case no or few resources are available for developing original stated preference studies in the study site. However, the transfer error can be significant. In practice, we do not know what the size of the real error introduced by using value transfer is. There is a strong case for employing further sensitivity of e.g. 20% around the values we have recommended to account for value transfer error. There is clearly also an extremely good case for undertaking primary research in Flanders.
- On the one hand, the estimated health effects do not give an exhaustive view of all possible health impacts of air pollution. On the other hand, there is also some overlap in the effects that we have described.

Despite the large uncertainty surrounding individual estimates, we can be confident about the order of magnitude of the yearly marginal "cost of illness" due to PM2.5, PM10 and ozone (a few dozens of millions EUR per 10µg/m³). If we also take into account the "subjective" health costs, our estimates run in the billion EUR.

The most important health effects identified in this study are:

- Premature deaths due to chronic exposure to PM2.5
- Premature deaths due to acute exposure to PM10

- Premature deaths due to acute exposure to ozone
- The pain and suffering following from lower respiratory problems attributed to PM10
- The pain and suffering following from restricted activity attributed to acute exposure to PM2.5
- The productivity losses and the lost household work due to acute exposure to PM2.5
- The pain and suffering due to minor restricted activity days (amongst adults) and to cough days (amongst children), attributed to acute exposure to ozone.

The essential problem is that all our calculations are based upon epidemiological studies and administrative databases that have not been organised with the research questions of this study in mind. In an ideal world, a study of environment related health costs would start with an inventory of the health endpoints that need to be studied. Based upon this inventory, one would draft an exhaustive and non-overlapping list of studies that need to be performed in Flanders. Due to budget restrictions, this is probably not possible, and one will have to do with the results of "ad hoc" studies that have been undertaken in a different context and with other objectives in mind.

However, this does not need to come at a large cost: our research has shown that relatively small changes in existing structural surveys (such as the Belgian Health Surveys) and in the organisation of administrative databases could lead to significant improvements compared to the current situation – we refer to the complete report for more details on this issue.

With respect to the valuation of the "subjective" health impacts, we identified three options that Flemish authorities may consider. The options include:

- rely on existing estimates, transferred from other countries;
- replicate the most recent stated preference exercises in Flanders;
- develop a bespoke valuation method to fit the Flemish context.

In the complete report, we have evaluated these options, drawing out the relative merits and limitations of each. The key trade-off is between cost (option (a) being free whilst option (c) costing circa €250,000) and level of certainty in the values. At present, transferred values from other studies can be used. However, they bring with them a high degree of uncertainty, resulting from the methods used to derive the original values and the transfer process itself.

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