Analysis of the CAFE cost benefit analysis

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ABSTRACT

This report discusses a few aspects of the Cost Benefits Analysis that was developed within the context of the Clean Air For Europe (CAFE) programme of the European Commission. The aspects considered are the monetisation of impacts of air pollution on human health and the results of a statistical uncertainty analysis.

The CAFE programme has resulted in the publication of the Thematic Strategy on Air Pollution (TSAP) and this TSAP is also considered in the report.

KEYWORDS

Clean Air For Europe, CAFE, Cost Benefit Analysis, Thematic Strategy, VSL, Value of a Statistical Life, VOLY, Value of One Life Year

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SUMMARY

This report discusses a few aspects of the Cost Benefits Analysis that was developed within the context of the Clean Air For Europe (CAFE) programme of the European Commission. The aspects considered are the monetisation of impacts of air pollution on human health and the results of a statistical uncertainty analysis.

The CAFE programme has resulted in the publication of the Thematic Strategy on Air Pollution (TSAP) and this TSAP is also considered in the report.

The main conclusions of the study are:

1. The CAFE CBA methodology suffers from fundamental shortcomings in terms of the CBA metric and the lack of using a marginal analysis. This leads to some wrong conclusions in terms of scenario justification.

2. In this study we argue that within the air pollution context of CAFE the relevant monetisation metric is Value of One Life Year (VOLY) rather than the Value of a Statistical Life (VSL) metric that has been used in the CAFE CBA methodology.

3. Values for VOLY as obtained by the Commission's NewExt study are very much higher than those found in other studies.

4. Defra[1] commissioned a study which is a high quality study directly eliciting VOLY and giving quite reasonable VOLY results.

5. An alternative approach, based on life insurance policies, is discussed in this report. This approach gives an interesting different angle to the subject of mortality valuation leading to much lower estimates. However, a direct interpretation of these results is not clear.

6. The economic justification of the CAFE TSAP ambition level is not very robust, it is strongly affected by reasonable variations of relevant parameters.

The CAFE CBA methodology could be considerably improved by taking the comments above into account, especially by using a proper marginal analysis (comment 1) and using VOLY rather than VSL (comment 2). Using a more balanced VOLY value, also accounting for the outcomes of the Defra study, is also strongly recommended (comments 3 and 4). This would also improve the robustness of the TSAP when varying relevant parameters (comment 6).

[1] UK Department for Environment, Food and Rural Affairs

1. INTRODUCTION

1.1. HEALTH BENEFITS IN CAFE

This report discusses two aspects of the Cost Benefit Analysis (CBA) that was developed within the context of the Clean Air For Europe (CAFE) programme of the European Commission, namely the valuation of health impacts and the results of an uncertainty analysis.

The health benefits considered in the CAFE CBA fall in two categories: mortality and morbidity. The two main pollutants considered for human health impacts are Particulate Matter (PM) and ozone. For PM the focus is especially on the $PM_{2.5}$ fraction: PM with an aerodynamic diameter smaller than 2.5 micrometer. This fraction is considered to be more harmful to human health than PM_{10}.

The following overview of monetised health impacts, based on the CAFE CBA results, will give the reader an idea on the distribution of the monetised impacts over the different health endpoints. For the PM morbidity category, a further subdivision is given as well.

Health impact	Sub-category	Sub category contribution to total health impact	Contribution to total monetised health impact
$PM_{2.5}$ Chronic mortality			68%
$PM_{2.5}$ Morbidity			29%
	Chronic bronchitis (27+)	13%	
	Restricted Activity Days RAD	10%	
	Lower Respiratory Symptoms	6%	
Ozone Acute Mortality plus Morbidity			3%

It is very clear from these data that according to the CAFE CBA methodology the health impacts of PM (mortality plus morbidity) are very dominant, with PM Chronic mortality being 68% of the total monetised impacts.

1.2. CAFE SCENARIOS

Within the CAFE programme the analysis was done using so-named *scenarios*. Each scenario is defined by a certain given *improvement in environmental and health impacts,* or by what is often referred to as the *ambition level*. Then using an optimisation technique a set of abatement measures is determined at country level which will give the most cost-effective way, calculated at the aggregated European level, to obtain this prescribed ambition level. The time horizon for the scenarios is the year 2020. The year 2000 is the baseline year.

The range of the ambition levels is determined by two endpoints. The lower ambition level is given by the so-named CLE 2020 scenario which implies that Currently agreed Legislation is Enacted upon. The high end of the ambition spectrum is the so-named MTFR scenario where the Maximum Technically Feasible Reductions are being applied. Unlike the other CAFE scenarios these two endpoint scenarios are not optimised and are not driven by a given ambition level.

Ideally speaking a set of intermediate scenarios should be selected covering the whole spectrum in an even way in terms of closing the gap between CLE 2020 and MTFR. In the later stages of the CAFE programme several sets of scenarios were used. Each set contained three scenarios called A, B and C, where the A scenario represented the lowest ambition level. It must be noted that this A scenario already implied a 50% closure of the gap between CLE and MTFR in terms of health impacts. Thus the A scenario already implied a considerable ambition in terms of impacts and thus in costs.

The CAFE programme culminated in the adoption of the so-named Thematic Strategy on Air Pollution, which will be important for future ambition levels in air quality legislation. The ambition level of the TSAP is between A and B.

1.3. OVERALL STRUCTURE OF CAFE COST BENEFIT ANALYSIS

The Cost Benefit Analysis methodology as used for CAFE is described in three volumes [6, 7, 8].

A complete human health Cost Benefit Analysis with the CAFE programme consists of the following steps:

1. Starting from the total dataset of European emission inventories, as available in the EMEP programme, a dispersion calculation is made with the EMEP model using a given set of meteorological conditions (for a specific year or for average conditions). This results in a set of European wide concentrations fields for all relevant pollutants. The information is available on a grid covering Europe.

2. Using these concentration fields as input the RAINS model calculates the population-weighted impacts of the pollutants. In other words, the exposure of the European population to the calculated pollutant concentrations is calculated. For every scenario run with RAINS the costs per country for the selected set of measures is also calculated.

3. Using concentration response functions, it is possible to estimate the health impacts of the relevant pollutants per EU country in terms of numbers of cases (both for mortality and morbidity). Some of these health impacts are estimated directly within RAINS (e.g. PM chronic mortality and ozone acute mortality), but the full health impact estimation is done separately using the CAFE CBA methodology as developed by AEAT [6, 7, 8].

4. The health impacts are then expressed in monetary terms using the valuation parameters as developed within the CAFE CBA. These valuated health

impacts are in fact always ‘damages’ because they are a valuation of the negative impacts of pollution on human health.

5. When comparing different CAFE scenarios, the improvement in health impacts (thus the lowering of the negative health effects) going from one scenario to the next can then be compared directly with the increase in costs between the two scenarios. In other words, for two scenarios one can calculate the marginal increase in ‘benefits’ (valuation of lower health impacts) and compare those with the increase in marginal costs. The net marginal benefits are then simply calculated as the difference between the marginal benefits and the marginal costs. This *difference* is the correct metric to be used in any CBA as opposed to the *ratio* of the benefits over the costs. See [21, 22] for further discussion.

Following up on point 5 it should be emphasised that unfortunately the CAFE CBA methodology does not *consistently* use a full marginal analysis. A marginal analysis was shown amongst other results in [14], but not in the most recent report on TSAP [15]. For the MTFR scenario an incorrect application of CBA economics by the CAFE CBA team leads to the wrong conclusion that MTFR has a positive net benefit. Moreover in both reports the benefit cost *ratio* is used as a metric, rather than using the difference.

We recommend using a consistent marginal approach with the correct metric of marginal benefits minus marginal costs, as this would improve the quality of the analysis.

It will be clear that uncertainties are present in each step of the analysis and these will influence the resulting reliability of the final metric: the difference between the marginal benefits and the marginal costs. For example, in the first step the quality of the emission inventories as well as the choice of the meteorological conditions will have an impact on the values found for the benefits.

The uncertainty analysis presented in this report considers the uncertainties in the valuation of the health impacts rather then non-health impacts, because within the CAFE CBA methodology certain choices have been made which can be replaced by equally reasonable, plausible alternatives. Using the uncertainty analysis presented here the influence of these choices on the CBA will be clarified.

The most important choices within the CAFE CBA methodology are:

- The figure used for the Value of One Life Year VOLY, as the few available studies to elicit VOLY directly give quite different results compared to the NewExt study as will be discussed in detail in section 2.1.1.
- The slope of the concentration response function used for $PM_{2.5}$ all cause mortality and for the morbidity endpoints chronic bronchitis and restricted activity days (RADs). The assumption that there is no concentration threshold below which both mortality and morbidity occur is also a very critical assumption. See sections 2.2 and 3.4.4 for more details.
- The economic value assigned to chronic bronchitis.

Of course there are several other sources of uncertainty which have not been considered here, e.g. in emission estimates and in air quality modelling. We have focussed on the effects of uncertainties in the health impacts monetisation because these can be quantified and they prove to have a major impact on the results of the Cost Benefit Analysis.

2. VALUATION OF HEALTH IMPACTS

In order to be able to quantify the human health impact of certain air quality scenarios for use in a formal Cost Benefit Analysis (CBA), one needs to assign a monetary value to these impacts. There are two main categories of human health impact: mortality and morbidity.

2.1. VALUATION OF MORTALITY

A crucial part of any formal Cost Benefit Analysis (CBA) methodology, including the one as developed for the CAFE programme, is the quantification of health benefits related to mortality.

In this context two metrics are often used: the Value of a Statistical Life VSL (sometimes called the Value of a Prevented Fatality VPF) and the Value of One Life Year or Value of One Year Lost (VOLY or VOYL).

The VSL is the amount of money that a community of people are willing to pay to lower the risk of an anonymous instantaneous premature death within that community (e.g. by certain traffic safety measures). Thus VSL is a limited amount, whereas of course to save a specific individual in danger, usually no means are spared. VSL is calculated by dividing the amount people are willing to pay by the change in mortality risk. VSL is the correct metric in the context of observable deaths such as in traffic accidents.

The VOLY is defined as the amount of money that people are willing to pay for one year of additional life expectancy.

There is an ongoing discussion in the literature as to what metric is appropriate in what context. The fact that there are many studies trying to elicit VSL values, but only a handful of studies doing the same for VOLY sometimes is a reason for researchers to use VSL. VSL is used quite often in the USA, see e.g. [22] for more information.

In this report however, we conform to the position taken by the researchers of the ExternE project supported by the European Commission DG research. See [16, page 140 and Table 7.3] and also [5] for an extensive discussion and overview of the pros and cons of using VSL and VOLY in different contexts. This position is also shared by the research team of the more recent NewExt study [10, p. 12].

The ExternE researchers state that in the context of air pollution VOLY is a more appropriate and defensible metric than VSL. This is because for air pollution the impact is not instantaneous, but it is the cumulative result of years of exposure (so-named chronic mortality), so that the number of deaths is not observable. As a result, it is impossible to tell whether a given exposure has resulted in a small number of people losing a large amount of life expectancy or in a lot of people losing a small amount of life expectancy. Only the average number of years of life lost can be calculated and so it is clear that indeed VOLY is indeed the only correct metric in this context.

As an additional remark it should be noted that considering changes in remaining life expectancy is fully consistent with *long term epidemiological studies* (so-named cohort studies) which allow the calculation of total population life expectancy losses, but *not* the number of deaths attributable to air pollution [5]. In other words, using epidemiological evidence as is done within the CAFE programme, again dictates that VOLY, rather than VSL, be adopted.

In this report we fully support this reasoning and therefore use VOLY rather than VSL to monetise health impacts. Using VSL based quantifications next to VOLY as a 'sensitivity case' as done by the CAFE CBA team [14, 15] is in our opinion methodologically wrong and cannot therefore provide valuable information, even as sensitivity study.

The actual numerical value of VOLY (or VSL for that matter) can be determined in different ways. There are two main approaches: so-named stated preference methods and revealed preference methods.

In the first approach survey respondents are asked to explicitly state monetary values for a hypothetical change in risk or in life expectancy. The results are then scaled back to the value for VSL or VOLY. To measure VOLY directly the survey should try to elicit the value of a change in life expectancy directly and not a change in risk of dying as this requires a non-trivial conversion from VSL to VOLY. There is a very large number of studies eliciting VSL and deriving VOLY from that, but there are not many studies directly eliciting VOLY.

In a well-known variant of the second approach, the so-named hedonic pricing method, one tries to obtain the implicit value of an attribute by comparing prices and attribute levels. A concrete example is looking at wages for jobs with different risk levels: by accepting jobs with higher risks for a higher wage, people implicitly use a value for VOLY or VSL. Other factors influencing the job choice should be filtered out using statistical methods. Another variant of the revealed preference method looks at risk averting behaviour of people e.g. the amount of money that people spend on smoke detectors or the use of seat belts by motorists. From this information one can again try to elicit a number for VOLY/VSL.

Within the CAFE CBA framework a choice was made to use a stated preference method, a so-named Willingness To Pay (WTP) approach using so-named contingent valuation techniques. Using a survey technique, respondents are being asked what they would be willing to pay for a small benefit, typically a small reduction in their risk of dying or a change in life expectancy of one month. Then the answers are scaled to give a value for the VOLY which is of course the monetary value associated with <u>one year</u> of life expectancy change.

As a survey technique is being used, the answers of the respondents, and thus the value of the derived VOLY, unavoidably show a certain range which can be quite large. Also, different surveys, applying different questions to the respondents, will unavoidably give different results.

The CAFE CBA team have selected the NewExt [10] study results for VOLY as their choice of central value in the CAFE CBA methodology. In the next section we will compare the NewExt results with those of other comparable studies and we will demonstrate that the *NewExt values are much higher* than those found with these other studies.

In section 2.1.2 we will also discuss a quite different approach to value mortality using a large life insurance policy database.

2.1.1. Stated preference studies for eliciting VOLY

The NewExt study results are described in [2] and [10]. The study is based on a survey that was conducted in three countries, the UK, France and Italy. The NewExt standard report [2] gives the pooled results of these surveys and these have been used for the CAFE CBA as well. The NewExt values for VOLY derived from the pooled results are 52,000 € based on the median of the full sample distribution and 118,000 € based on the mean.

NewExt results are described both in terms of VSL and VOLY. There are many studies that try to elicit VSL values as compared to VOLY (which is not the most appropriate metric within an air pollution context as was discussed in detail in section 2.1), however the NewExt authors state that they were at the time aware of *only two other studies* that have employed *stated preference techniques for placing a value on life expectancy changes directly trying to elicit VOLY values* [2, page 22]. This is confirmed in [10]. It should be noted that the NewExt study itself also elicits VSL and then derives VOLY values from the VSL data.

The two studies directly eliciting VOLY as mentioned by the NewExt team are the study by Johannesson and Johansson [4], which is based on a Swedish survey and the study of Morris and Hammitt [9], which is based on two US surveys, one phrased in terms of a risk reduction of annual mortality and one in terms of a direct change in life expectancy. For more details on both these studies see Appendix 1.

It is important to note that Morris and Hammitt [9] report that in a survey people find it much harder to value a change in risk reduction than a direct change in life expectancy expressed in e.g. months.

The NewExt authors clearly state that the two studies [4, 9] *seem to imply much lower VOLY figures* than those produced by their NewExt study [2, page 22].

In the meantime a new study by Chilton et al. [3] and commissioned by the UK Department for Environment, Food and Rural Affairs (Defra) has become available. We consider this to be a high quality study, with a well thought-through methodology and led by a research team which is very experienced in this field. The Defra study is phrased in terms of a direct change in life expectancy (in months) and not in terms of mortality risk changes. This is a very strong advantage of this study, as people understand a direct life expectancy change much better, as is confirmed by Desaigues et al in [11].

The Defra study asks three separate sets of UK respondents for WTP in terms of a life expectancy increase of 1, 3 or 6 months respectively, both in normal and in poor health, so in total six datasets for three different population samples are available. For more details see Appendix 1.

A summary of the results of the Defra study is given in Table 1. The WTP results of the survey are in terms of a life expectancy increase of 1, 3 or 6 months and they need to be normalised to Value of One Life Year (VOLY) by multiplying with a factor 12, 4 and 2 respectively. As the WTP amount asked for was phrased in terms of a yearly payment for the rest of the life of the respondent, the WTP given is also multiplied by 78, which is the current life expectancy in the UK. The final results of this scaling are given in Table 1. The VOLY values given in the table are based on the mean of the survey sample distribution or on the median.

Looking at the results in Table 1 (for Normal and Poor heath separately) we note that although the direct WTP results from the survey increase with the life expectancy (LE) asked for (1, 3 or 6 months), the scaling to one year with a factor 12, 4 and 2 respectively causes the VOLY to decrease with the LE asked for.

As said, in general for a larger LE change, the mean and the median Defra WTP values itself, which are the figures coming directly from the survey, are indeed higher than for a shorter LE change. This is not self-evident, because the WTP values for the three different LE values are given by three *different* groups of respondents. However the increase in the WTP values is not fully proportional to the increase in LE and, after scaling, this causes the decrease in VOLY for larger LE values as shown in the table.

Table 1 Summary of results from Defra VOLY study (N: normal health, P: poor health)

Based on:	**1 month N**	**1 month P**	**3 months N**	**3 months P**	**6 months N**	**6 months N**
Mean	€ 45,298	€ 12,421	€ 22,771	€ 5,693	€ 12,705	€ 2,168
Median	€ 15,360	€ 1,783	€ 2,218	€ 0	€ 2,663	€ 395

As a second observation we note that most Defra values are much lower than the NewExt values. This could be caused by the fact that this is a UK-only study. From the NewExt study, which looks at the UK, Italy and France, it is clear that WTP values are different per country. The UK median WTP is lowest whereas Italy WTP is highest being 188% of the UK median WTP. But even if we would consider median VOLY figures that would be twice as high as the Defra median VOLY values, we would still find VOLY figures that are still significantly larger than the NewExt median VOLY of 52,000 €, namely 30,720; 3,566; 4,436; 0; 5,326 and 790 € (using Table 1, second row). Thus the conclusion remains valid that the Defra VOLY figures are lower than those of NewExt.

When asking for a LE increase in Normal health (N) one can assume that the valuation then implicitly includes morbidity. In other words, using the Normal health values, one should not add a separate morbidity valuation as this would be double counting.

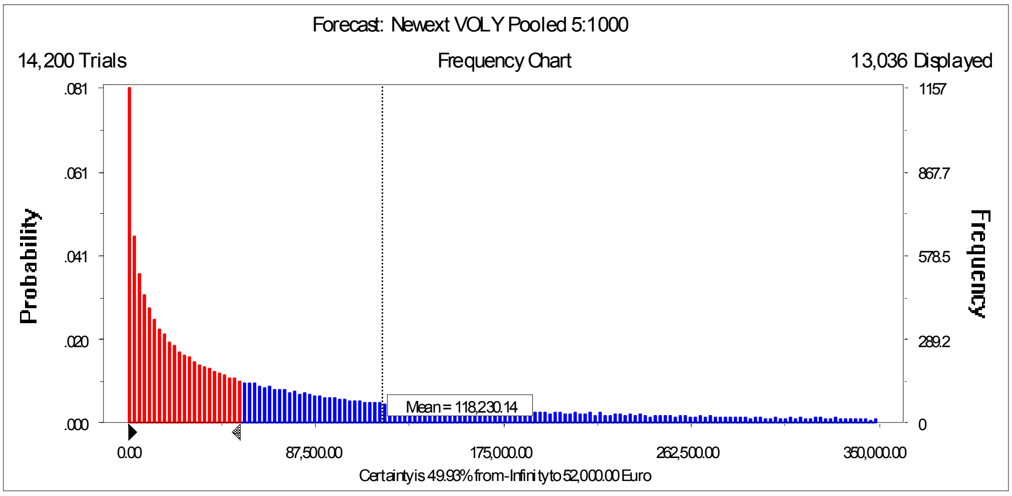
For the NewExt and the Defra studies, sufficient data is available to obtain the full probability distributions of the WTP answer sets.

Curve fits using a Weibull two-parameter distribution as they were used and discussed by the NewExt authors themselves have been used by us as well. We have generated the relevant Weibull fits for the Defra study using the full data set as made available to CONCAWE by the authors. For [4], we have requested the authors for the Weibull parameters as they were not given in the original paper and out of the four available options we have used the distribution giving the largest range.

The other study [9], gives a range VOLY values based on a set of four very specific curve fits as developed by the authors. Analysing the raw data using Weibull curve fits resulted in a smaller VOLY range, which has not been used here, instead the published wider range has been used.

The VOLY distributions as found from the surveys are always very non-symmetrical ones, strongly skewed towards zero. This is demonstrated in Figure 1 where the VOLY distribution as found by the NewExt authors (pooled data, 5:1000 risk reduction case) is shown. The mean value is indicated and the median is the split between the blue and red areas of the curve.

Figure 1 Probability distribution for NewExt VOLY [10]



Please note that Figure 1 clearly shows that a certain amount of people declare a WTP value of zero (0). This is true for all surveys discussed here. The respondents take the full survey, but select a WTP of zero, these are called the 'non-protest' zeros. Very often when performing the survey there is also a significant group of respondents who refuse to assign a WTP e.g. because they are of the opinion that the government should pay for the benefits asked for. These respondents are called 'protest-zeros' and they are always ignored in the survey WTP analysis.

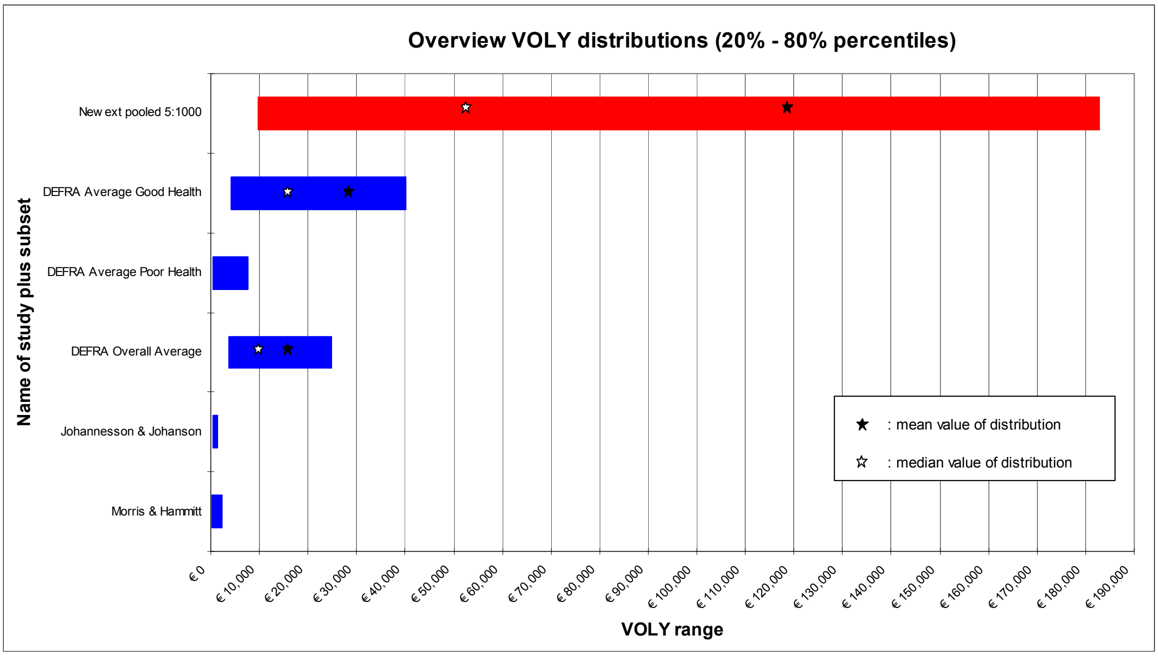
As a general remark it can be stated that the mean VOLY of a certain study is very sensitive to the curve fitting technique being used, as the mean is very sensitive to the precise description of the right-hand tail of the probability distribution representing the high VOLY values. The *median* is defined as the mid-point of a distribution, with half of the sample less than or equal to the median, and half of the sample greater than or equal to the median value. One can expect that the median value is less sensitive to a limited number of extreme high values than the mean and it is indeed true that to characterise strongly skewed distributions the median is usually a much more *robust* statistic than the mean, see also [1].

The next figure compares the range of VOLY values found from all four studies. Where a full distribution was available the 20% to 80% percentile range is shown, for the other study [9] the whole range of the mean VOLY as given in the paper is being used here.

For the studies with the largest ranges mean and median values are also indicated.

It is very clear from the figure that the NewExt study not only has the widest range, but also has a strong bias towards very high mean and median values. It definitely is not a good representation of what has been found for VOLY in quite comparable studies.

Figure 2 Range of VOLY values found in the different studies.



In Table 2 an overview of the VOLY ranges as well as the values for mean and median are given.

Table 2 Numerical VOLY data of the different WTP studies

Study	20%	80%	Range	Median	Mean	Ratio median
NewExt pooled 5:1000	9,700	183,000	173,000	52,000	118,000	-
Defra average good health	4,200	40,000	36,000	14,000	27,000	4
Defra average poor health	400	7,800	7,400	1,900	6,800	27
Defra overall average	3,800	24,800	21,000	10,200	16,800	5
Johannesson et al.	400	1,500	1,100			
Morris et al.	140	2,300	2,200	700	1500	75

The column 'Ratio median' gives the ratio of the NewExt median VOLY value and the median VOLY of the different studies. These numbers reinforce the conclusion that the NewExt VOLY values are much higher than those found in the other eliciting studies.

2.1.2. Life insurance approach

2.1.2.1. Methodology and interpretation

As a totally different way of looking at effects of life expectancy increases, CONCAWE has conducted a study which involves data on life insurance policies for three different countries (United Kingdom, France and Italy).

The basic approach is as follows. For every country a very large database with life insurance policies plus relevant details is available. Also per country we have detailed information on mortality rates (or equivalent life expectancy) in age bands and for both sexes.

By adjusting the known mortality rates we can now increase the life expectancy at birth for both sexes by 1 year (365 days). Assuming the total sum of premiums paid over the whole policy running period remains constant, we can then consider the corresponding change in annual premium that reflects the change in life expectancy. In other words, based on a constant total premium, increasing the life expectancy will decrease the annual premium to be paid and we consider this premium differential for a one year increase in life expectancy at birth.

The *total* monetary increase associated with an additional year of life expectancy is then found by multiplying the *annual* premium differential by an assumed average life expectancy of 72 years.

It is clear that this method can be classified as a revealed preference method as it is clearly based on actual (premium) payments being paid by people.

The interpretation of the resulting figures is less clear. The derived premium differential is not related to what people are willing to pay for a life expectancy increase or a mortality risk decrease because a life insurance is taken to give a certain cover *after* the policy holder has actually died. But the life insurance itself is intended to cover part of the loss that occurs after death.

Interesting aspects of this work are the enormous amount of observations (life insurance policies) on which it is based (about 22 million in both UK and France and 11 million in Italy) and the fact that this is about payments that have actually been made by people as opposed to an expressed willingness to pay.

2.1.2.2. Results

When using a life expectancy increase of 1 year at birth the results for the total benefit are as follows:

Table 3 Total monetary increase associated with a 1 year life expectancy increase at birth based on life insurance premiums

Country	Total benefit (€)
United Kingdom	3,067
France	3,714
Italy	5,805

The United Kingdom figure does not include Death In Service (DIS) pensions, although this type of life insurance is quite common in the UK. Including the DIS benefits the UK figure for the total benefits would be 13,611 €.

It is clear that differences between countries can be quite significant. The UK has the lowest figure, the result for France is 121% of this and for Italy the result is 189%. It is remarkable that the NewExt study, trying to elicit Willingness To Pay figures for certain reductions in mortality risks, finds the same kind of differences between these three countries. Again taking the UK result as a reference, from [10, table 3] it can be seen that the figure for France is 124% and the figure for Italy is 188% of the UK figure. The explanation for this is not clear, the finding could be fortuitous.

As a variation the premium differential was also calculated using a one month and one week life extension compared to the above-mentioned one year. Per country the total benefits are almost directly proportional with the life extension period, a result which is to be expected.

The final interpretation of Table 3 is not clear due to reasons mentioned above. There do not appear to be any studies in the published literature that used similar methods and data sources with which to compare these findings. As such, additional research using other data sources and similar methods to replicate the results would be informative. However, the values in Table 3 are notably similar to findings reported in stated preference surveys by Morris and Hammitt [9], Johannesson and Johansson [4], and the Defra [3] study – see Figure 2, Table 2 and Appendix 1.

2.2. VALUATION OF MORBIDITY

The valuation of morbidity is even more uncertain than that of mortality. However, within the CAFE CBA methodology this uncertainty is not properly addressed.

For the bronchitis valuation the following problems can be mentioned:

- The concentration response function used to derive monetary estimates is based on a single older U.S. study [17]. Thus U.S. background disease rates are used and these are implicitly assumed to be the same for Europe. This study made no attempt to determine whether or not a threshold existed for the effect, yet a no threshold approach is used in the CBA. This problem is exacerbated by the fact that the levels of pollution in the study were very high compared to those prevailing in Europe today.
- The findings were not statistically significant at the 5% level, raising the question of whether they are real or not.
- The findings are likely confounded by smoking, by far the largest factor in the etiology of bronchitis and presumed to not occur in the study population. The high lung cancer rates in males versus females appear to indicate smoking did occur in this population.
- The exposure data are based on estimates for total suspended particulates (TSP), which are large coarse size PM. These estimates then need to be converted to PM_{10}, and finally $PM_{2.5}$. Airport visibility data were also used to estimate fine PM levels. The methods used for these conversions are unclear and add significant uncertainty.
- Attributing bronchitis to fine rather than coarse PM is clinically implausible, as chronic bronchitis is a disease of the upper airways where coarse PM is deposited.
- The value used to monetise bronchitis events was based on a single Canadian-based study [20] without consideration for differences in baseline rates or costs of health care between Europe and Canada.

For the Restricted Activity Days (RADs) the following issues were identified:

- This concentration response function is again based on single old U.S. study [18, 19] in locations/time where photochemical air pollution was high, raising concern for confounding/double counting with other pollutants in particular ozone.
- RAD incidence is highly subject to confounding by socioeconomic and other factors not controlled in the study. These include time spent outdoors, health practices including how RADs are recorded, age, race, education, income, marital status, employment conditions/rates and smoking rates. In the study used, high city-to-city differences were observed. Even greater differences are expected when extrapolating results to Europe

We conclude that the concentration response functions and economic values used in the morbidity valuation were highly uncertain.

3. UNCERTAINTY ANALYSIS OF THE CAFE CBA

3.1. FOLLOWED APPROACH

Given the RAINS results as input, the CAFE CBA methodology gives a calculation procedure that in the end produces monetised health impacts for PM and ozone for every RAINS scenario. There are two health impact categories: mortality and morbidity.

Within the CAFE CBA methodology certain parameter choices have been made which have a direct impact on the results of the health impact valuation. One of the most important parameters is the VOLY (Value Of a Life Year). The calculated mortality valuation is directly proportional to VOLY. As was demonstrated earlier in this report (section 2.1.1) the VOLY is determined using surveys and therefore inherently has a certain statistical distribution. In the standard CAFE CBA approach two 'single point' calculations are made: one using the median of the VOLY and one using the mean. This results in two 'single point' estimates of the health benefits. Of course one loses a lot of information in this way and it would be much better to use the full statistical distribution of the VOLY to get a better idea of the inherent spread in the health benefits resulting from the spread in the VOLY. In this section two ways to take this inherent distribution into account will be explored.

In fact, it is possible to do an analysis using the full statistical distribution. The approach is simply to perform a very large number of 'single point' calculations, each time selecting a value for VOLY in a random process where the chance of picking a certain VOLY-value is given by the statistical distribution of the VOLY. After performing say 20,000 to 30,000 of these 'single point' calculations it is clear that we will also get a distribution of values for the health benefits. This distribution then gives us a good 'picture' of the spread in the health benefits caused by the spread in VOLY. The mathematical term for such an approach is Monte Carlo analysis and there is commercial software available to perform these analyses from within a spreadsheet.

The software tool Crystal Ball has been used for the current analysis. Using this tool it is also possible to look at the impact of the statistical spread of a number of (independent) parameters *simultaneously*.

3.2. CENTRAL VALUES OF CAFE CBA BASED ON MEDIAN VOLY

Before we start looking at the impact on the CAFE CBA of different kinds of uncertainty we first present the 'central' estimates of benefits and costs as presented in [14, 15]. In the table below the VOLY median values are presented. In [14, 15] also VOLY mean, VSL median and VSL mean results are given, but these are presented here because, as discussed above, we do not advocate the use of VSL or mean values, see section 2.1 and section 2.1.1.

In the table below all relevant CAFE scenarios are shown to give the complete picture. The annualised 'damages' are the sum of PM mortality, PM morbidity, ozone mortality, ozone morbidity and non-health impacts (crops, materials). Compared to CLE 2020 the other scenarios show lower damages and the difference are called 'benefits'. The marginal benefits given in a certain column are the difference in damages between the scenario of that column and the previous scenario. The same is true for the marginal costs. Annualised costs are all with respect to CLE 2020, the costs of CLE 2020 itself are 65,862 million € (M€) per year. The costs of the other scenarios include the so-called Euro 5/6 standards for the transport sector.

Table 4 Overview 'central' values CAFE CBA based on VOLY median values, all values in million € (M€) per year.

	CLE 2020	A	TSAP	B	C	MTFR
Annualised 'damages'	191,100	153,535	148,861	145,237	141,093	134,198
Marginal Annual Benefits		37,565	4,674	3,624	4,144	6,895
Annualised Costs		5,923	7,100	10,679	14,852	39,720
Marginal Costs		5,923	1,177	3,579	4,173	24,868
Marginal Benefits minus Marginal Costs		**31,642**	**3,497**	**45**	**-29**	**-17,973**

3.3. ASSUMPTIONS USED IN THE CAFE CBA UNCERTAINTY ANALYSIS

Using the Monte Carlo approach as discussed in the previous section, the adopted Thematic Strategy for Air Pollution (TSAP) scenario will be put in perspective with two other scenarios, A and B from the so-named (final) D23 set as well as with the MTFR scenario. See section 1.2 for more information on the CAFE scenarios. Compared to the TSAP the A and B scenario have a lower and higher ambition level respectively, although in absolute terms even the A scenario already has a high ambition, see section 1.2 and further discussion below.

The actual numerical results of applying the CAFE CBA methodology to the different CAFE scenarios and the TSAP are given in two reports [14, 15].

For the statistical analysis calculations the following assumptions have been made:

1. For the statistical distribution of the VOLY two philosophies have been used.
    a. In the first part of our analysis we look at the impact of the underlying VOLY distribution for one particular study. Here we directly mimic the behaviour of the respondents in a kind of 'voting' process as we look at the survey sample distribution of the VOLY value directly. See section 3.4.1 for a further clarification of this voting process. The used single-study VOLY distribution is the so-named Weibull distribution as mentioned by the NewExt authors themselves [2]. The Weibull probability is a flexible distribution often used in reliability engineering and also often used to describe VOLY distributions. In its usual form it has two parameters (a shape and a scale parameter), but sometimes a location parameter is added. Following [2] the NewExt VOLY has a scale parameter of 503.64 and a shape parameter of 0.67427. The location parameter is not used. As a variation we have looked at the VOLY as elicited by the Defra study [3].

   b. In the second part of the analysis we use a more common approach for the VOLY parameter using now a distribution around a representative value. In this report a normal distribution is being used with several variations for the average (or central or representative) value and a given standard deviation of 30%.

2. In the second part of the analysis where a representative VOLY distribution is used, the following distribution has been used for the (annualised) costs of each scenario: a normal distribution with a standard deviation equal to 20% of the mean value μ. This implies that the 99% confidence interval of the annual costs distribution is (0.5·μ, 1.5·μ) which is a realistic assumption for the uncertainties in the costs data. The mean values μ used for the annualised costs are of course exactly the values used in the CAFE CBA and reported in [14, 15] for the different scenarios.
3. For the morbidity valuation the default is the standard CAFE CBA figures, but as a variation we have also looked at cases where morbidity has not been valuated either because of the highly uncertain nature of these numbers or because the Defra Normal Health VOLY values already implicitly contain a morbidity contribution anyway.

3.4. RESULTS UNCERTAINTY ANALYSIS WITH FULL VOLY DISTRIBUTION

3.4.1. Reference case

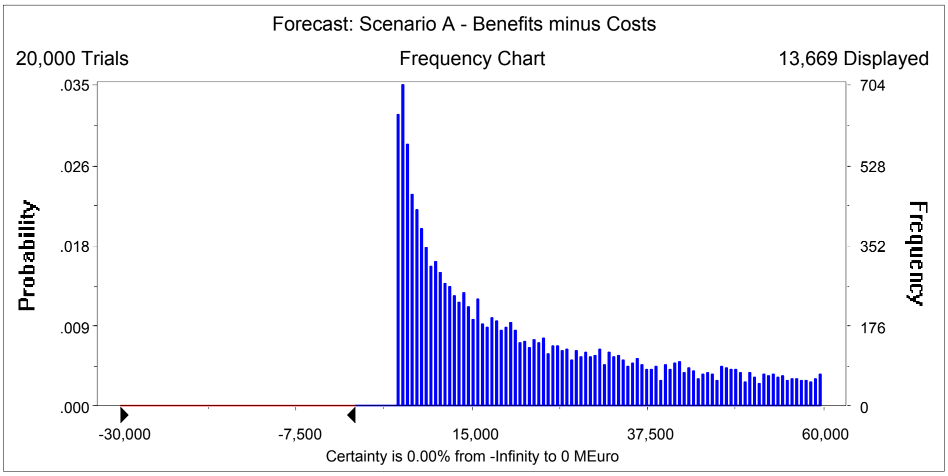
This is the standard CAFE CBA result where the NewExt full (sample) distribution is used. Results are shown for the A, TSAP, B and MTFR scenario.

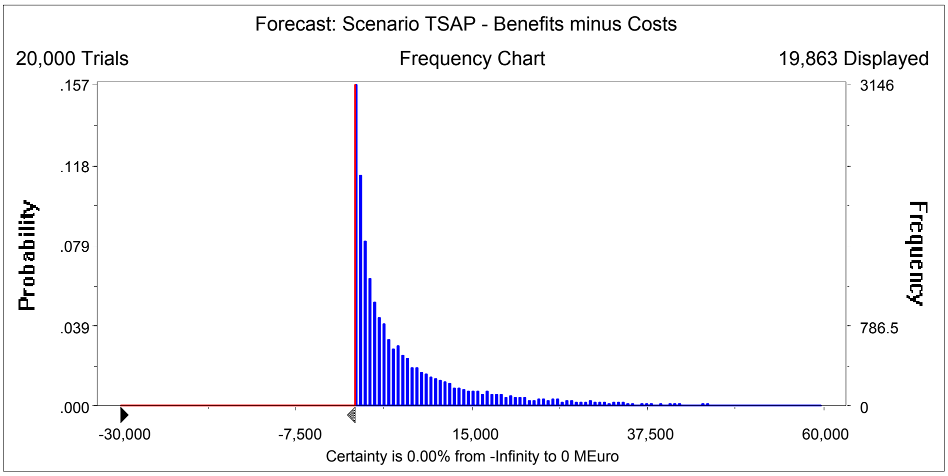
The figures below show the full statistical distribution of the proper CBA metric '<u>difference</u> between marginal benefits and marginal costs'.

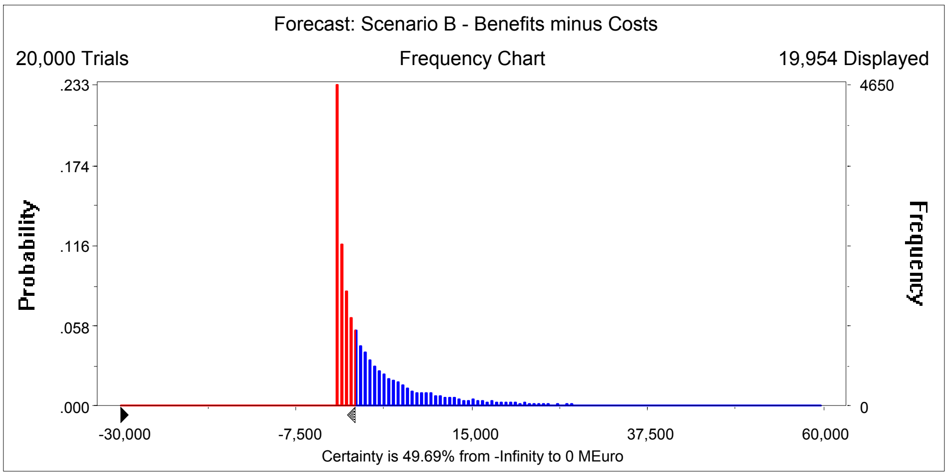
In these and all following figures the horizontal scale gives the net benefit in M€ (million €) and the vertical scale gives the probability. The horizontal scale endpoints are -30,000 M€ to 60,000 M€ in this chapter and -30,000 M€ to 30,000 M€ in the next chapter.

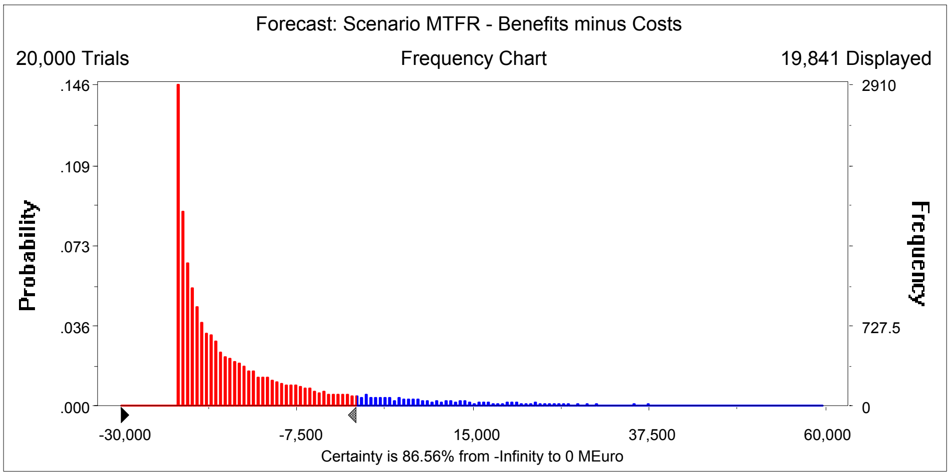
The figures can be interpreted as an analysis of the 'voting' behaviour of the respondents: whenever a VOLY value taken from the full VOLY distribution would imply a marginal cost that is greater than the marginal benefit, a 'No' vote is given, represented by the colour red (net benefit less than zero). The colour blue is used to indicate 'Yes' votes where marginal benefits exceed marginal costs. So the figures represent the impact of the distribution of VOLY values across the survey sample and thus, assuming the NewExt study is a correct representation, the range of VOLY across the population.

Figure 3 Standard CAFE CBA results, full NewExt VOLY distribution









From the figures it is very clear that even assuming that the NewExt VOLY distribution is a representative one, which is in our opinion not the case, the MTFR scenario can never be justified. Not less than 86% of the respondents would favour a VOLY value that implies marginal costs that <u>exceed</u> marginal benefits and they would therefore see MTFR as not being justified economically. Please note again that statements made by the CAFE CBA authors that MTFR is justified [14, 15] are not based on marginal costs and benefits, but on the absolute ones and this is simply a wrong way of using cost benefit analysis.

For the B scenario there is a 49% ‘No’ vote. For the lower ambition scenarios A and TSAP there are only ‘Yes’ votes.

3.4.2. Impact of morbidity

As a variation we have run the Reference case of section 3.4.1, but now without accounting for morbidity. This simply results in a shift of the graphs to the left. The net effect is that the TSAP scenario would get about 29% ‘No’ votes.

As the shapes of the distributions do not change very much the corresponding figures are not shown here.

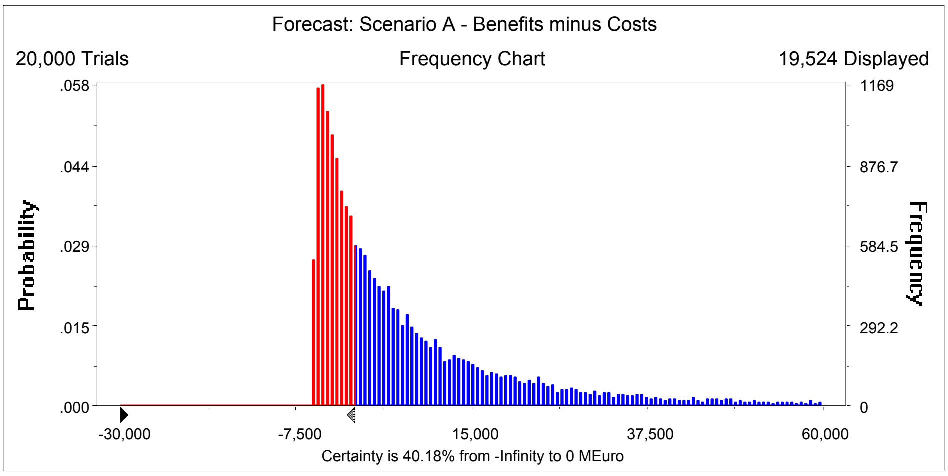
3.4.3. Defra VOLY variation

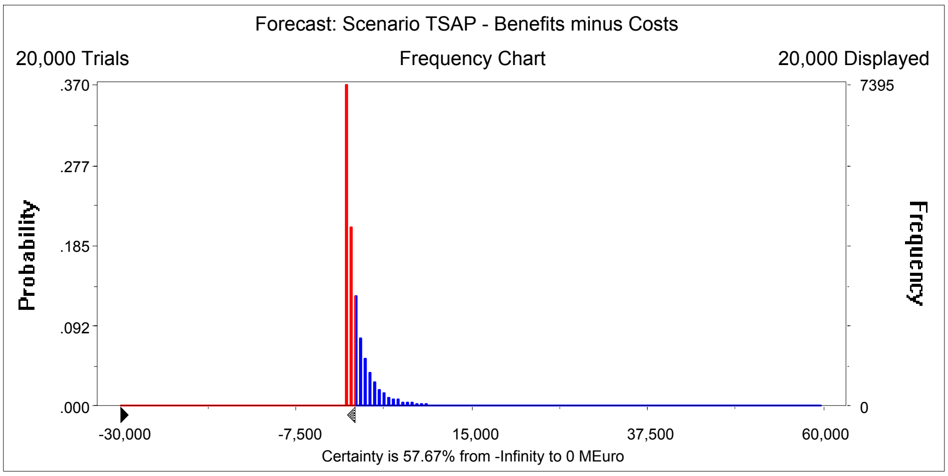
An interesting variation of the reference case is replacing the NewExt full distribution by the Defra full distribution, which is much less extreme in its values than NewExt, see Figure 2 and the discussion in section 2.1.1. As there are three independent data sets in the Defra study (corresponding to 1, 3 and 6 months of life expectancy increase), we have taken the *average* of the three full VOLY Weibull distributions for Normal Health, an exercise which is very easy to perform in Crystal Ball although the resulting distribution is of course a complex one and no longer an exact Weibull distribution.

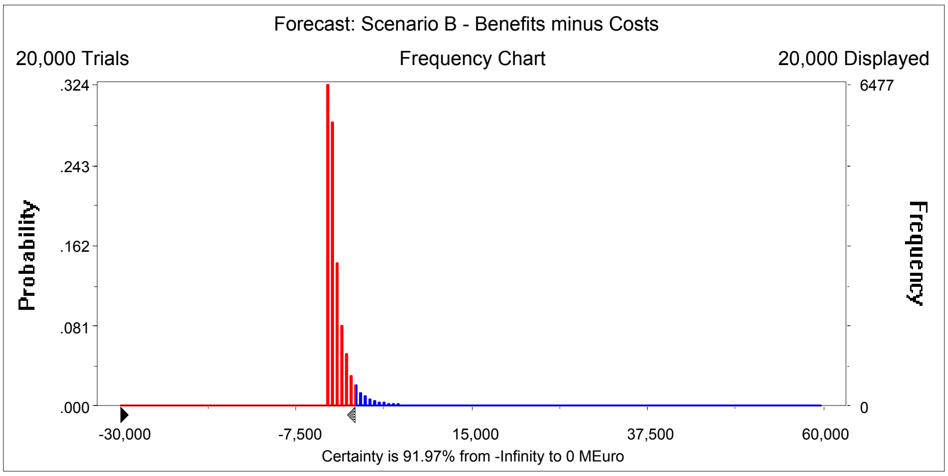
As we have used the VOLY distributions for Normal Health, we also have set the morbidity contribution to zero, because the Normal Health values will already include an implicit valuation of morbidity and we do want to avoid double-counting.

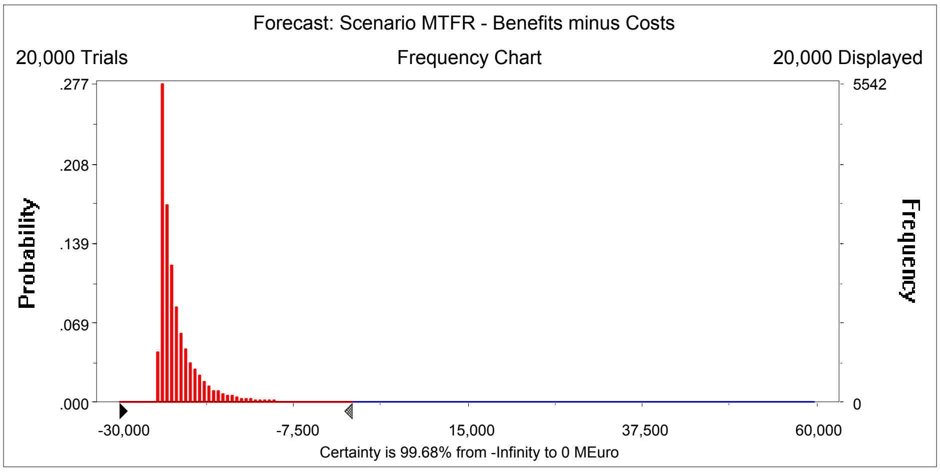
The results are given below.

Figure 4 Variation of reference case with full average Defra distribution









Note that in this case the TSAP scenario would get almost 60% of 'No' votes. This means that, using what is in our opinion a more acceptable VOLY distribution, the TSAP ambition level seems not very well justified.

The TSAP net benefits distribution has a mean of about 500 M€ and a median of -300 M€.

The MTFR scenario is now completely out of the picture: more than 99% of the votes would call this scenario not justified.

3.4.4. Variations of Defra VOLY with alternative PM chronic mortality dose-response function

To estimate the impact of $PM_{2.5}$ on chronic mortality one needs a concentration response function CRF which enables a quantification of the change in chronic mortality with a change in $PM_{2.5}$ concentrations. The concentration response function is assumed to be linear without a threshold so the ratio of change in mortality with the concentration change is constant and equal to the slope of the CRF. Information on this slope can be obtained from epidemiological studies although this is a complicated exercise.

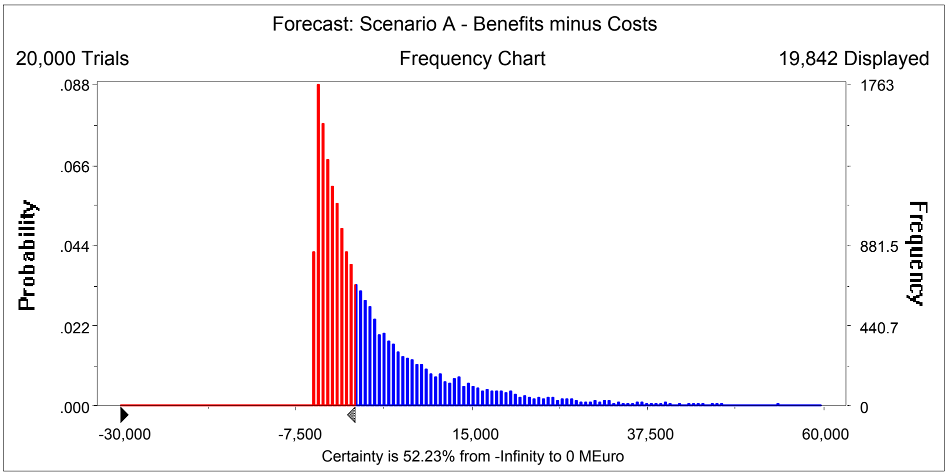
For the CAFE CBA the CRF used implies a 6% all cause mortality change per 10 $\mu g/m^3$ $PM_{2.5}$ change. However, other analyses of the data give rise to a different CRF slope. Here we will consider as an alternative a slope of 2% as per Krewski et al. [12] in which study the PM mortality was adjusted for the confounding effects of SO_2 in the atmosphere. This is a reasonable alternate case to consider since in Europe today, the SO_2 levels are quite low relative to those in the U.S. during the study period. Further, there is a substantial toxicology and human clinical literature clearly indicating that exposure to particulate matter with SO_2 produces a much higher degree of respiratory effects than exposure to PM alone. A second alternative would be a 4% slope value as per Pope et al. [13] which considers a long time lag for PM effects as per the WHO Global Burden of Disease Study.

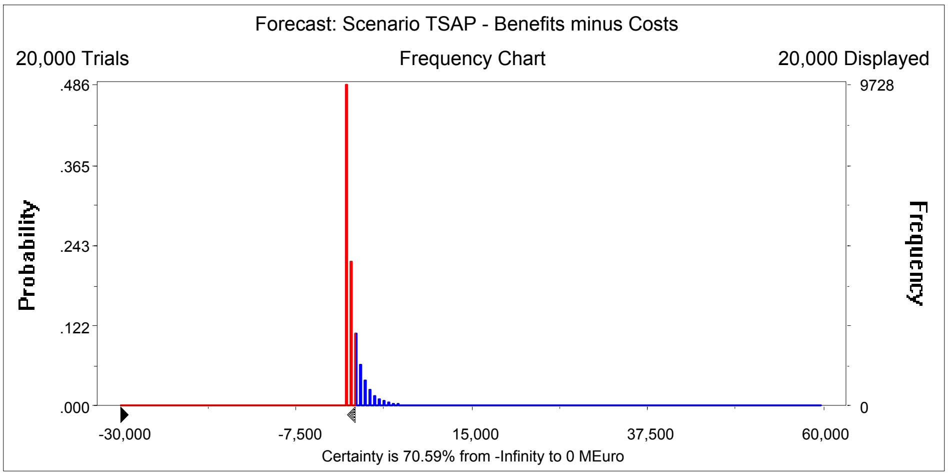
Only the 4% case is shown here, because this already leads to a situation where even the A scenario would get a vote of less than 50%, in fact there is a 52% probability of benefits minus costs being less than zero. The TSAP benefits minus costs distribution is largely below zero: there are 72% 'No' votes. So even with an intermediate value for the CRF slope the TSAP is seen to be strongly suboptimal in terms of benefits minus costs.

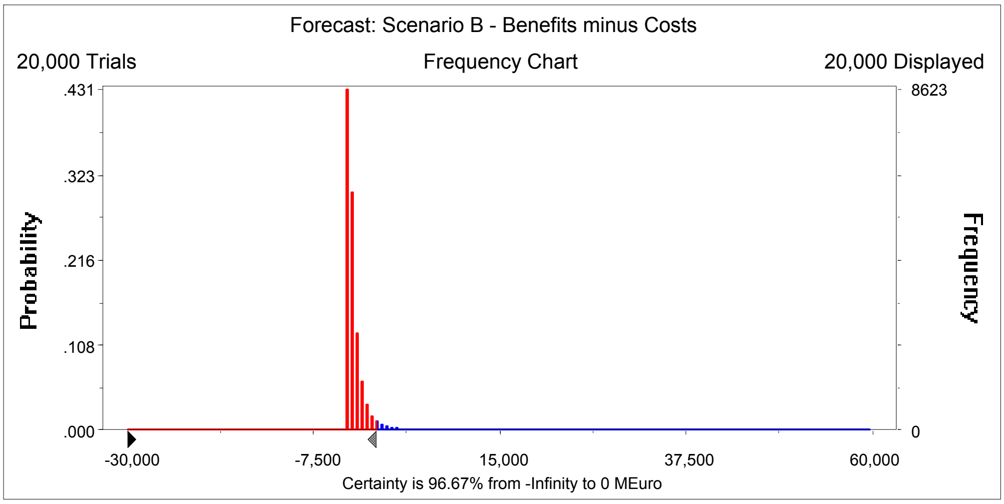
The results for the MTFR scenario are not shown here: as above it is fully unjustified.

Of course using the slope of 2% would shift the balance even more. Calculations show that the A scenario would have 73% of 'No' votes in this case and the TSAP would even have as much as 87% of 'No' votes.

Figure 5 Variation of reference case with full average Defra distribution and alternative exposure-response function slope







3.5. RESULTS UNCERTAINTY ANALYSIS WITH REPRESENTATIVE VOLY DISTRIBUTION

The following results are no longer using the 'voting' concept but use the more conventional approach of characterising the VOLY statistical spread by using a central value (average, mean) and a standard deviation. In all cases the standard deviation is taken to be 30%. We also assume that the VOLY has a normal distribution.

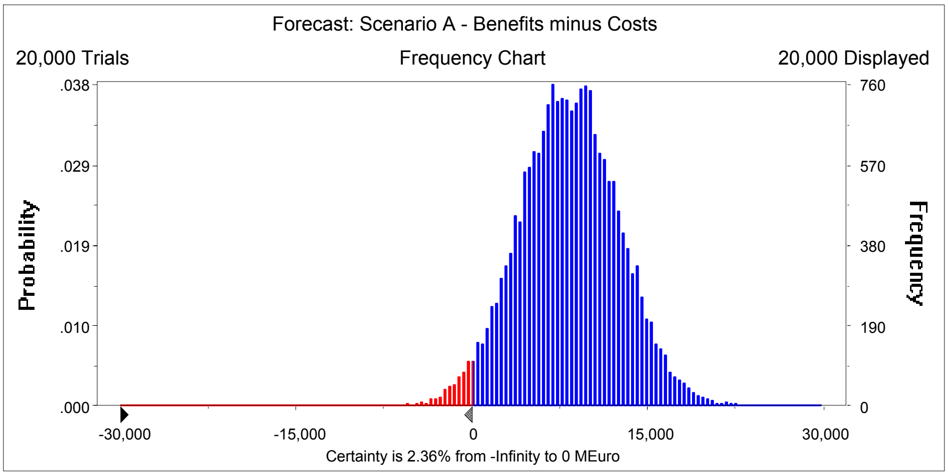
For all the results presented in this chapter for the costs a normal distribution was used as discussed in section 3.3 , bullet 3.

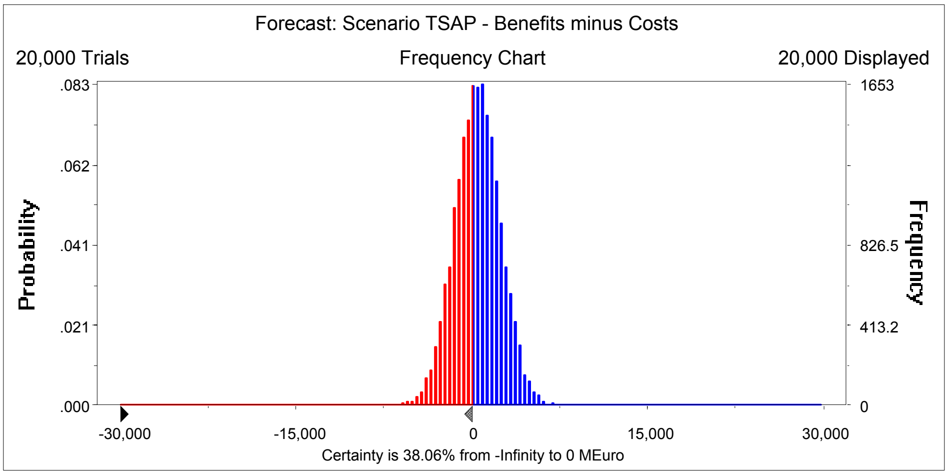
3.5.1. Defra average means as representative value

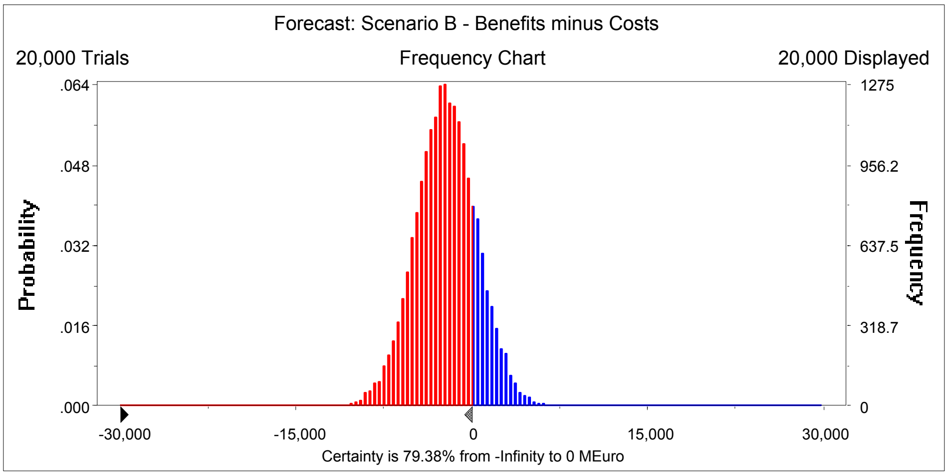
This case again uses the Defra study results as we judge the NewExt results to be too extreme. As a central VOLY value we take the average of the three Defra mean values for Normal Health, again assuming no separate morbidity valuation. This means that the VOLY has a central value of 26,925 €. The standard CRF slope of 6% is used.

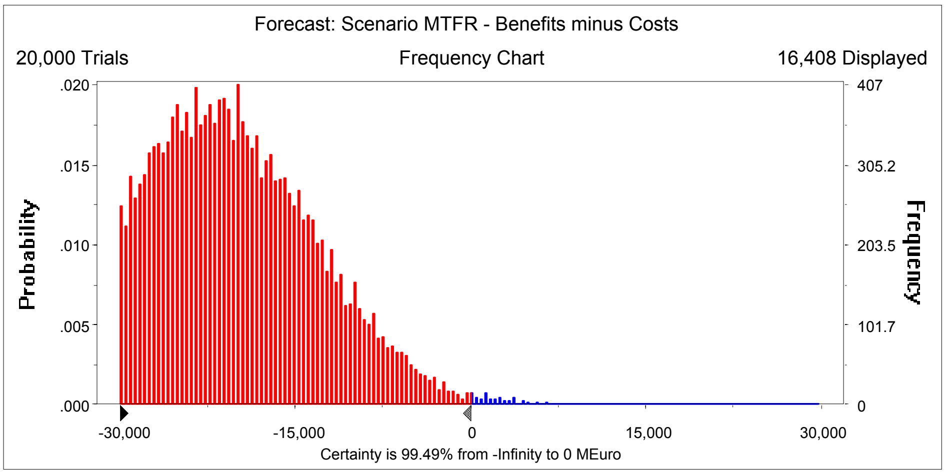
Results for the A, TSAP, B and MTFR scenario are given here in terms of marginal benefits minus marginal costs.

Figure 6 Representative VOLY; average of three Defra means









Note that the shape of the curves is now quite different than when using the full (Weibull) distributions and is much closer to a normal distribution. Also note that there are two parameters with a normal distribution: the VOLY and the costs figure.

The interpretation of the colours is quite simple: the areas of the curves where the net marginal benefits (marginal benefits minus marginal costs) are less than zero are coloured red. E.g. for the TSAP scenario there is now a 39% probability that the net benefits are negative, that is that marginal costs exceed the marginal benefits. Of course for a robust scenario selection one would like this probability to be small, at least smaller than 50%. Clearly the B and MTFR scenario have a high chance of 'regret investment' meaning that there is a high probability that costs will exceed benefits.

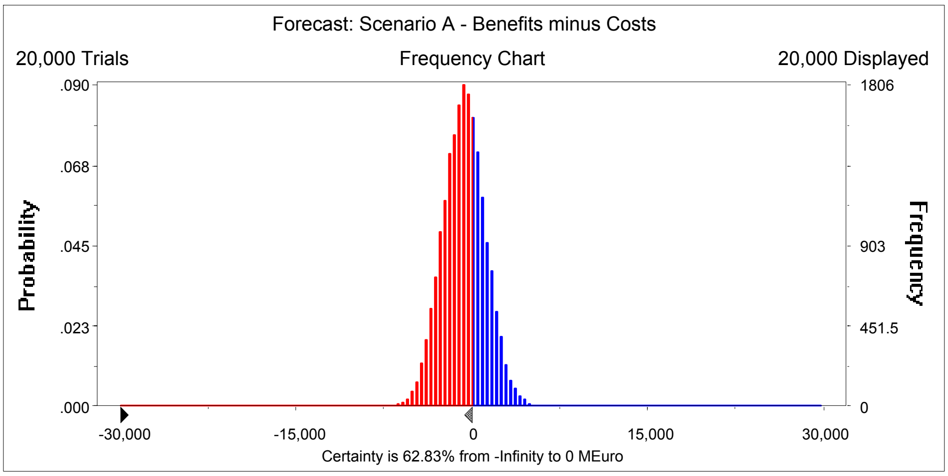
Again, this spread in the net marginal benefits is caused by the inherent statistical spread in the two parameters VOLY and 'annualised costs'.

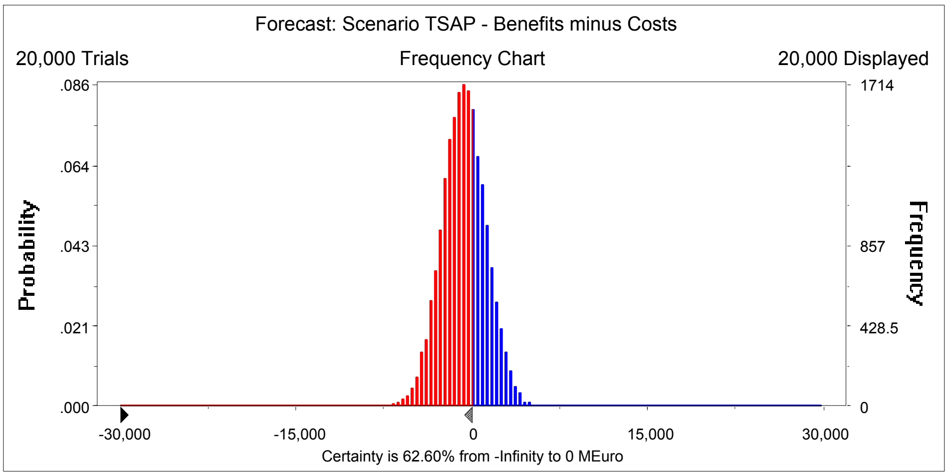
3.5.2. Defra average means as representative value with 2% CRF slope

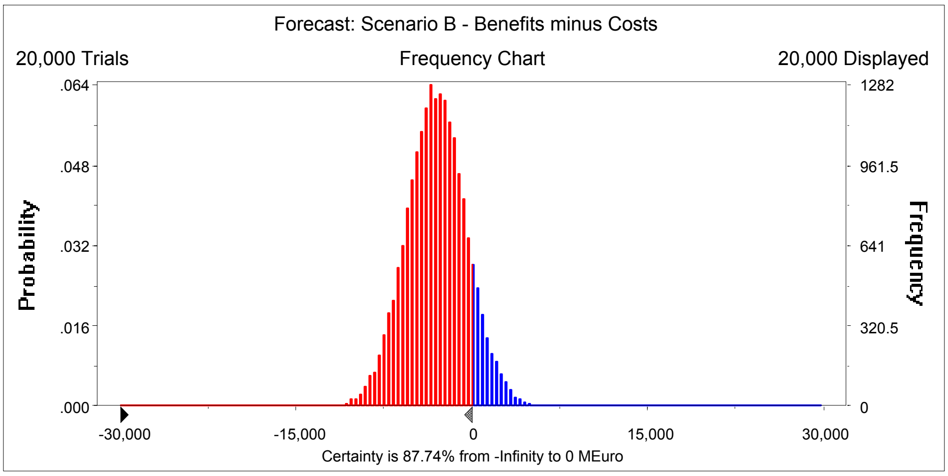
Building on the previous case, as an interesting parameter variation the slope of the CRF was set to what we consider its lowest plausible value of 2%. The 4% value will be discussed later on. Again the separate morbidity valuation is set to zero as we assume this included in the VOLY Normal Health results.

Results are given below, leaving out the MTFR graph which shows an almost 100% chance of regret investment.

Figure 7 Representative VOLY; Defra average means, CRF slope of 2%







The A and TSAP scenario show a 62-63% chance of regret investments.

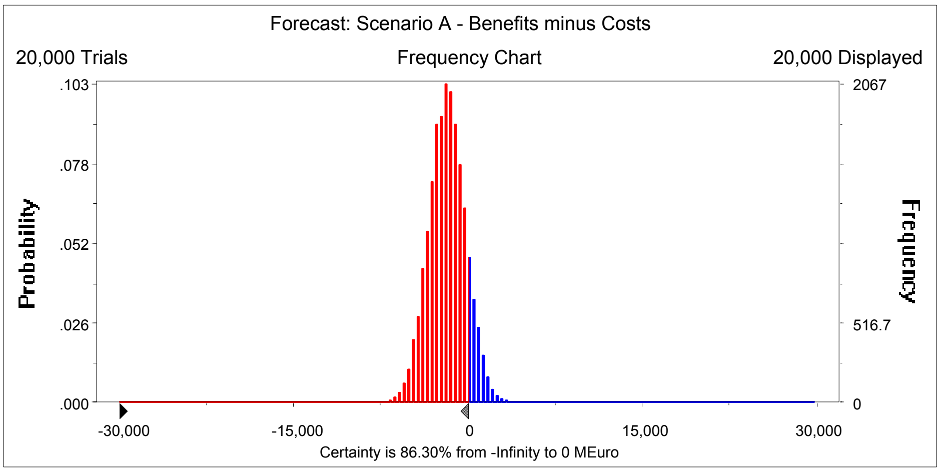
3.5.3. Defra average medians as representative value

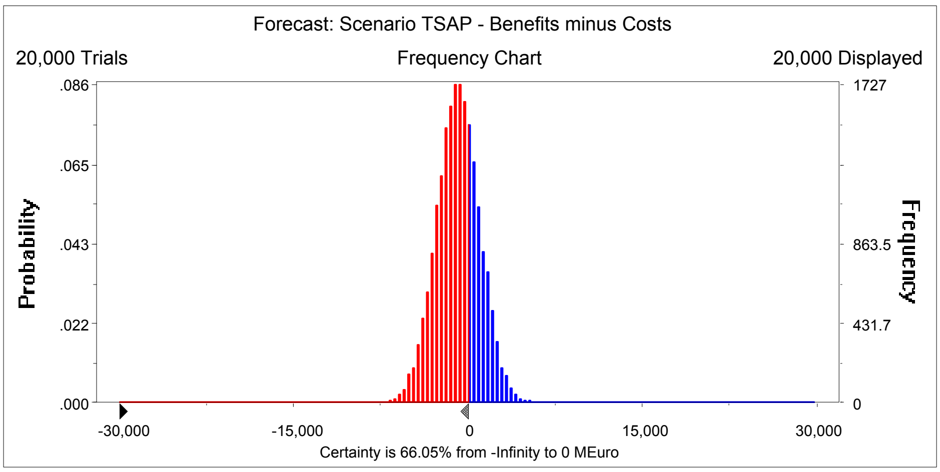
As was already noted in section 2.1.1, when dealing with such skewed parameter distributions as we have for VOLY in this CBA context, looking for a representative central parameter value the median is in general a much more robust choice than the mean in terms of characterising the typical value. See also the discussion in [1].

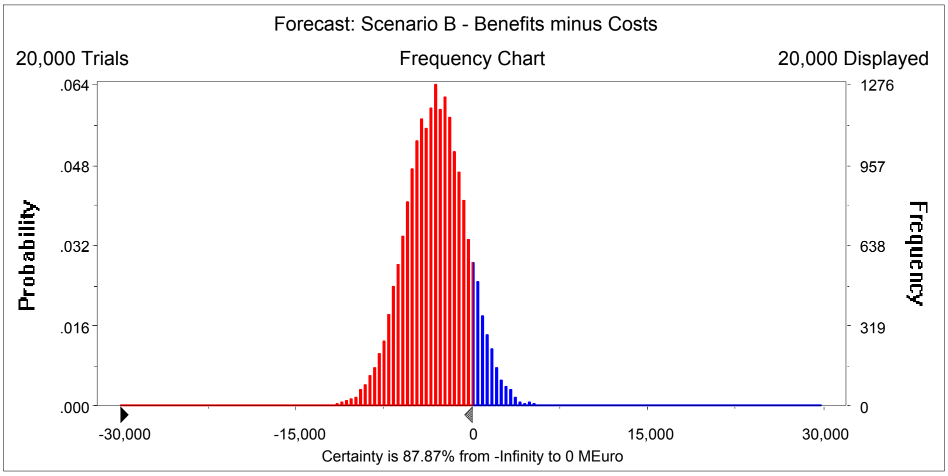
Therefore we have also analysed the case where the representative value is calculated as the average of the three Defra medians for Normal Health (no explicit morbidity). This results in a central value of 6,747 €. It is clear that compared to the mean the median value is much less influenced by the long but low right-hand side tail of the VOLY Weibull distribution.

The used CRF slope is the CAFE CBA value of 6%.

Figure 8 Representative VOLY; Defra average medians, CRF slope of 6%







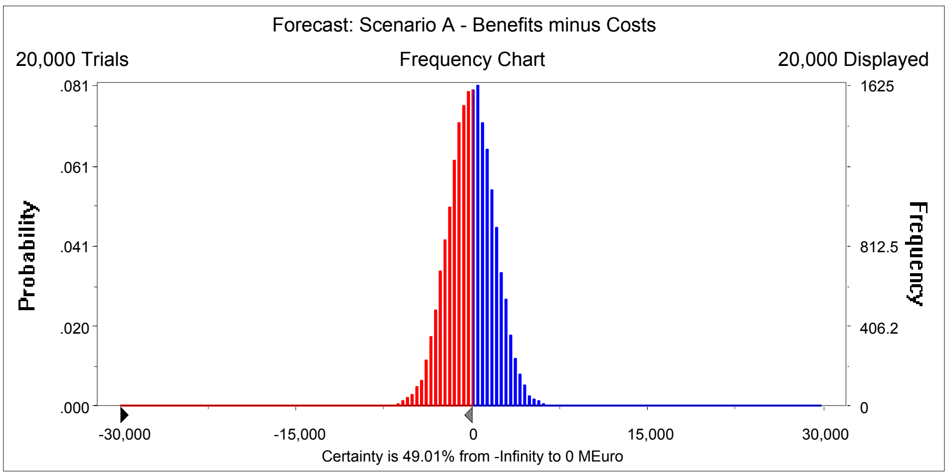
The impact of this variation is large: the A scenario now has a chance of generating negative net benefits of 87% and for the TSAP this number is 66%.

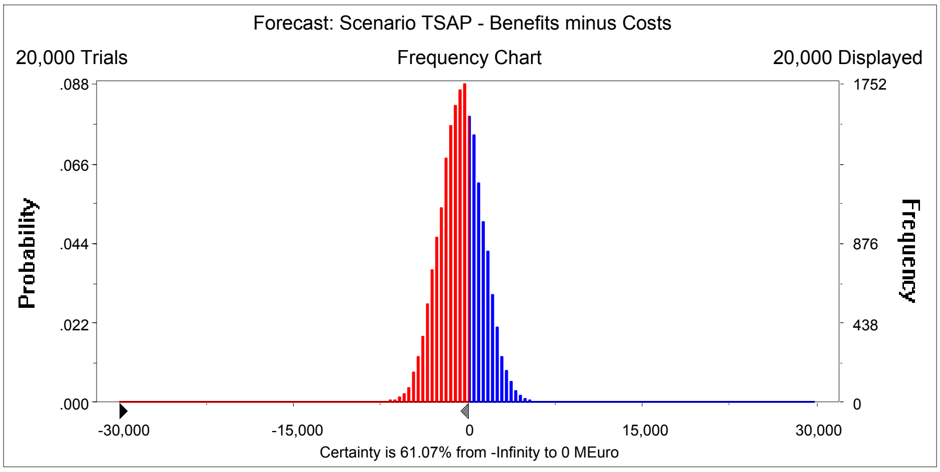
3.5.4. Combining several variations into a 'reasonable' case

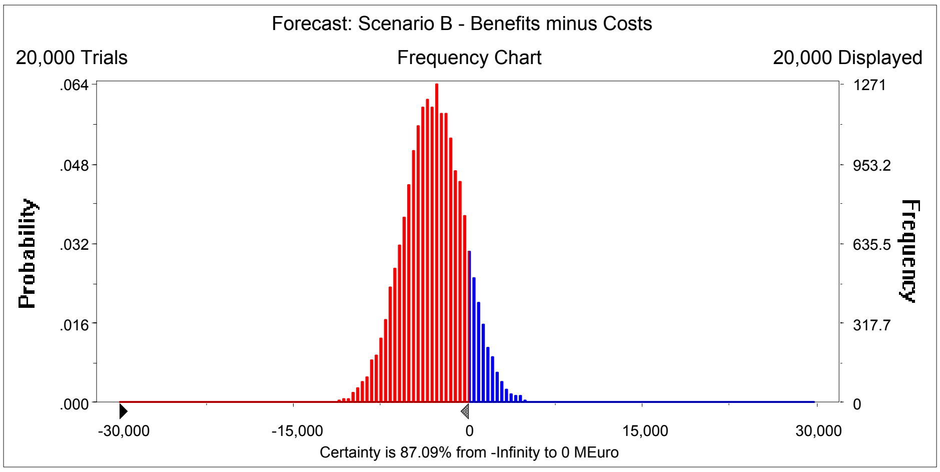
Looking at all the calculated results above, we can try to define a case which is reasonable and uses values that are not at the lowest or highest point of a range. This means that rather than NewExt we will use the Defra study. Also instead of using a CRF slope of 2% or 6% it seems more reasonable to use the intermediate value of 4%. And although using the median as a typical value is without doubt the most robust approach, we will not use the average of the Defra medians, which gives a rather low representative VOLY value, but instead the maximum of the three Defra Normal Health median numbers. This leads to a representative value of 15,360 € which is, taking all considerations as discussed in previous sections into account, a very reasonable number and definitely not too low. As before, using the Normal Health numbers implies that we use no additional explicit morbidity valuation.

The results for this quite 'reasonable' case are shown in the figures below.

Figure 9 'Reasonable' case; Defra maximum median, CRF slope of 4%







The conclusions for this case are clear: the A scenario looks to be precisely at the point where net benefits are zero (almost equal chance of either negative or positive net benefits), but the TSAP is well beyond that point in the sense that chances of receiving negative net benefits are fairly high (61%).

Of course, if one would have additional scenarios covering the gap between CLE 2020 and the A scenario, it could well be that the true optimum would be below the A ambition level as we are doing a marginal analysis here and a better description of the change in net benefits could modify our conclusions.

Also, for a robust scenario selection, one may argue that the '50-50' distribution of the A scenario for this case is not good enough, certainly taking the results of the previous section into account where a much lower but still defendable VOLY central value was used.

4. CONCLUSIONS AND RECOMMENDATIONS

1. The CAFE CBA methodology has two fundamental shortcomings:

   - It uses the wrong CBA metric

   - It does not use a proper marginal analysis.

This leads to some wrong conclusions in terms of scenario justification.

2. In the air pollution context of CAFE the relevant metric is VOLY rather than VSL.

3. NewExt VOLY numerical results are very much higher than those found in other studies.

4. Defra commissioned a high quality study directly eliciting VOLY. The results of this study have not been given sufficient attention in the CAFE CBA.

5. The life insurance approach gives an alternative to the subject of mortality valuation. The results suggest much lower estimates, although a direct interpretation of these results is not clear. Efforts to replicate the findings in different populations by different investigators would be informative, although it is worth noting that the findings are similar to several previous stated preference surveys.

6. The CAFE TSAP ambition level is not very robust when looking at the impact of reasonable parameter variations such as:

   - VOLY distribution (full sample distribution and distribution around a representative value)

   - PM concentration response functions (2, 4 or 6%)

   - Morbidity (with or without)

The CAFE CBA methodology could be considerably improved by taking the comments above into account, especially by using a proper marginal analysis (comment 1) and using VOLY rather than VSL (comment 2). Using a more balanced VOLY value, also accounting for the outcomes of the Defra study, is also strongly recommended (comments 3 and 4). This would also improve the robustness of the TSAP when varying relevant parameters (comment 6).

5. LIST OF ABBREVIATIONS AND ACRONYMS

A	Scenario from CAFE programme
B	Scenario from CAFE programme
C	Scenario from CAFE programme
CAFE	Clean Air For Europe, EU air quality programme
CBA	Cost Benefit Analysis
CLE	CAFE scenario Current Legislation Enacted
CRF	Concentration Response Function
EMEP	UN-ECE's cooperative programme for monitoring and evaluation of the long-range transmission of air pollutants in Europe
LE	Life Expectancy
MTFR	CAFE scenario Maximum Technically Feasible Reductions
PM	Particulate Matter
PM_x	PM with a nominal mean aerodynamic diameter less than or equal to x micrometer (x is 10 or 2.5 in this context)
RR	Risk reduction
TSAP	Thematic Strategy on Air Pollution
RAD	Restricted Activity Day
RAINS	Mathematical model used for CAFE (Regional Air Pollution Information and Simulation)
VOLY	Value of One Life Year
VPF	Value of a Prevented Fatality
VSL	Value of a Statistical Life
WHO	World Health Organization
WTP	Willingness To Pay

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APPENDIX 1 OVERVIEW OF STATED PREFERENCE STUDIES ELICITING VOLY

The NewExt reference paper

Reference

Alberini, A., Hunt, A., Markandya, A., 2004, *Willingness to Pay to reduce Mortality Risks: Evidence from a Three-Country Contingent Valuation Study*, Fondazione Eni Enrico Mattei Note di Lavorro Series, Nota di Lavorro 111.2004, September 2004

Target group

Persons aged between 40 and 75. Respondents from UK, France and Italy.

Type of WTP asked for

Reduction in risk of dying, metric is VSL

Specific questions

WTP for a risk reduction of 5 in 1000 to be experienced over the next 10 years (beginning immediately)

Same, but for 1 in 1000 risk reduction (no results reported here)

WTP for a risk reduction of 5 in 1000 to be experienced over the 10 years but beginning at age 70 (no results reported here)

Survey technique

Self-administered (computer), dichotomous choice questions, dichotomous choice follow-ups

Main conclusions

VSL are within and at the low end of the range recommended by DG Environment

No evidence that WTP (VSL) is lower for older persons

WTP responses combined with life expectancy implied by the 5 in 1000 risk reduction is used to estimate VOLY

VOLY for pooled results 52,000 € (median) and 118,000 € (mean)

Morris & Hammitt

<u>Reference</u>

Morris, J., Hammitt, J.K., 2001, *Using Life Expectancy to Communicate Benefits of Health Care Programs in Contingent Valuation Studies*, Medical Decision Making, Nov-Dec 2001, pp. 468-478, 2001.

<u>Target group</u>

US citizens, all younger than 60 (70)

<u>Type of WTP asked for</u>

Life expectancy increase, reduction in risk of dying, metric is VOLY

<u>Specific questions</u>

Half of the respondents were asked for WTP for a vaccine benefit expressed as a life expectancy gain

For the other half the equivalent benefit was expressed as a reduction in average annual chance of death

Each half was further split (in total 4 subsamples): two samples were asked to give WTP if the vaccine was given at age 60, the other two samples for a vaccine given at age 70

<u>Survey technique</u>

National random-digit-dial phone interviews followed by a follow-up phone interview after respondents had received a mailed packet of information

Double-bounded dichotomous WTP question

<u>Main conclusions</u>

Response rate 75%, of those 30% would not consider getting the vaccine

Life Expectancy method has greater validity than Risk Reduction method (scope test)

Life Expectancy also values higher than Risk Reduction

VOLY between $492 and $698

Johannesson & Johansson

Reference

Johannesson, M., Johansson, P-O., 1996, *To Be, or Not to Be, That Is the Question: An Empirical Study of the WTP for an Increased Life Expectancy at an Advanced Age*, J. of Risk and Uncertainty, volume 13, pp. 163-174, 1996.

Target group

Swedish citizens, aged 18-69

Type of WTP asked for

LE, metric is VOLY (directly measured)

Specific questions

Life expectancy increase of 1 year (10 instead of 11 years) at age 75 due to medical treatment, conditional on having survived until the age of 75

Survey technique

Binary WTP question (only one WTP value is mentioned, answer yes or no, if yes: ‘are you sure?’, no more questions), telephone interview.

Main conclusions

71% of the answers is ‘no’: many individuals seem to have a zero WTP

Average VOLY is $400 to $1500 depending on statistical estimation technique used

Defra commissioned study

Reference

Chilton, S., Covey, J., Jones-Lee, M., Loomes, G., Metcalf, H., 2004, *Valuation of health benefits associated with reductions in air pollution*, Defra publication PB 9413, May 2004.

Target group

UK citizens

Type of WTP asked for

Life Expectancy, metric is VOLY (directly measured)

Specific questions

WTP was asked for a life expectancy increase of 1, 3 or 6 months (three subsamples). For each sample: 1/3/6 months extra life in Normal and Poor health.

All respondents were also asked WTP for Avoiding Hospital Admissions & Avoiding Breathing Discomfort.

Survey technique

Ordering of cards with WTP values

Main conclusions

VOLY range:

Based on:	**1 month N**	**1 month P**	**3 months N**	**3 months P**	**6 months N**	**6 months N**
Mean	€ 45,298	€ 12,421	€ 22,771	€ 5,693	€ 12,705	€ 2,168
Median	€ 15,360	€ 1,783	€ 2,218	€ 0	€ 2,663	€ 395