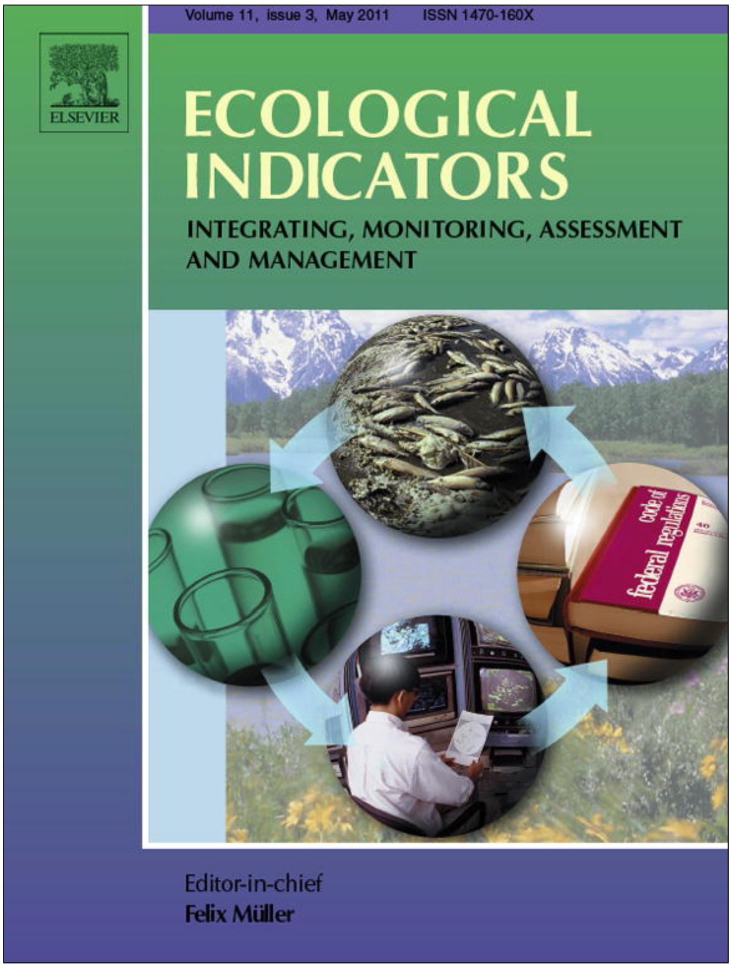
Volume 11, issue 3, May 2011 ISSN 1470-160X
ELSEVIER
ECOLOGICAL INDICATORS
INTEGRATING, MONITORING, ASSESSMENT AND MANAGEMENT
code of federal regulations
Editor-in-chief
Felix Müller

Ecological Indicators 11 (2011) 902–910

Contents lists available at ScienceDirect

Ecological Indicators

journal homepage: www.elsevier.com/locate/ecolind

Economic valuation of air pollution mortality: A 9-country contingent valuation survey of value of a life year (VOLY)

B. Desaigues[a], D. Ami[a], A. Bartczak[b], M. Braun-Kohlová[c], S. Chilton[d], M. Czajkowski[b], V. Farreras[e], A. Hunt[f], M. Hutchison[a], C. Jeanrenaud[g], P. Kaderjak[h], V. Máca[c], O. Markiewicz[b], A. Markowska[b], H. Metcalf[d], S. Navrud[i], J.S. Nielsen[j,k], R. Ortiz[f], S. Pellegrini[g], A. Rabl[l,*], R. Riera[e], M. Scasny[c], M.-E. Stoeckel[m], R. Szántó[h], J. Urban[c]

[a] *Université Paris 1, France*
[b] *University of Warsaw, Poland*
[c] *Charles University Prague, Czech Republic*
[d] *University of Newcastle, UK*
[e] *Universidad Autonoma Barcelona, Spain*
[f] *University of Bath, UK*
[g] *Université de Neuchatel, CH, Switzerland*
[h] *Corvinus University, Hungary*
[i] *Department of Economics and Resource Management, Norwegian University of Life Sciences, Norway*
[j] *National Environmental Research Institute, Denmark*
[k] *University of Southern Denmark, Denmark*
[l] *ARMINES/Ecole des Mines de Paris, France*
[m] *EIFER/Electricité de France, France*

ARTICLE INFO

Article history:
Received 15 October 2010
Received in revised form 1 December 2010
Accepted 5 December 2010

Keywords:
Air pollution
Mortality valuation
Life expectancy
Life years lost
Contingent valuation
Environmental policy

ABSTRACT

This paper provides a key element for the calculation of the damage costs of air pollution, namely the valuation of mortality, important because premature mortality makes by far the largest contribution. Whereas several studies have tried to quantify the cost of air pollution mortality by multiplying a number of deaths by the 'value of prevented fatality' (also known as 'value of statistical life'), we explain why such an approach is not correct and why one needs to evaluate the change in life expectancy due to air pollution. Therefore, an estimate for the monetary value of a life year (VOLY) is needed. The most appropriate method for determining VOLY is contingent valuation (CV). To determine VOLY for the EU, we have conducted a CV survey in 9 European countries: France, Spain, UK, Denmark, Germany, Switzerland, Czech Republic, Hungary, and Poland with a total sample size of 1463 persons. Based on the results from this 9-country CV survey we recommend a VOLY estimate of 40,000 € for cost–benefit analysis of air pollution policies for the European Union. As for confidence intervals, we argue that VOLY is at least 25,000 € and at the most 100,000 €.

1. Introduction

The damage cost, also called external cost, of a pollutant is an important ecological indicator, increasingly used by governments for the cost–benefit analysis of environmental regulations or for the determination of pollution taxes. For example, in the EU the CAFE (Clean Air for Europe) program of the Directorate General for Environment carried out a major cost–benefit analysis of proposed new regulations (Holland et al., 2005). It was largely based on the ExternE (External Costs of Energy) project series of the EU (ExternE, 1998; ExternE, 2005; www.externe.info). In the USA EPA uses cost–benefit analysis to recommend regulations for pollution control (see e.g. Abt, 2004), and a large study of external costs of air pollution was recently published by the National Research Council of the National Academies (NRC, 2009).

The calculation of the damage costs of pollution is a complex multidisciplinary undertaking. It requires detailed modeling of environmental pathways to determine how a given source of a pollutant increases the exposure of all affected receptors (people, agricultural crops, materials and ecosystems), followed by the use of exposure-response functions for each of the numerous possi-

Abbreviations: CV, contingent valuation; LE, life expectancy; NMC, New Member Countries (of EU); PPP, purchase power parity; VOLY, value of a life year; VPF, value of a prevented fatality; WTP, willingness-to-pay.

* Corresponding author. Tel.: +33 1 6928 0694.
E-mail address: ari.rabl@gmail.com (A. Rabl).

1470-160X/$ – see front matter © 2010 Elsevier Ltd. All rights reserved.
doi:10.1016/j.ecolind.2010.12.006

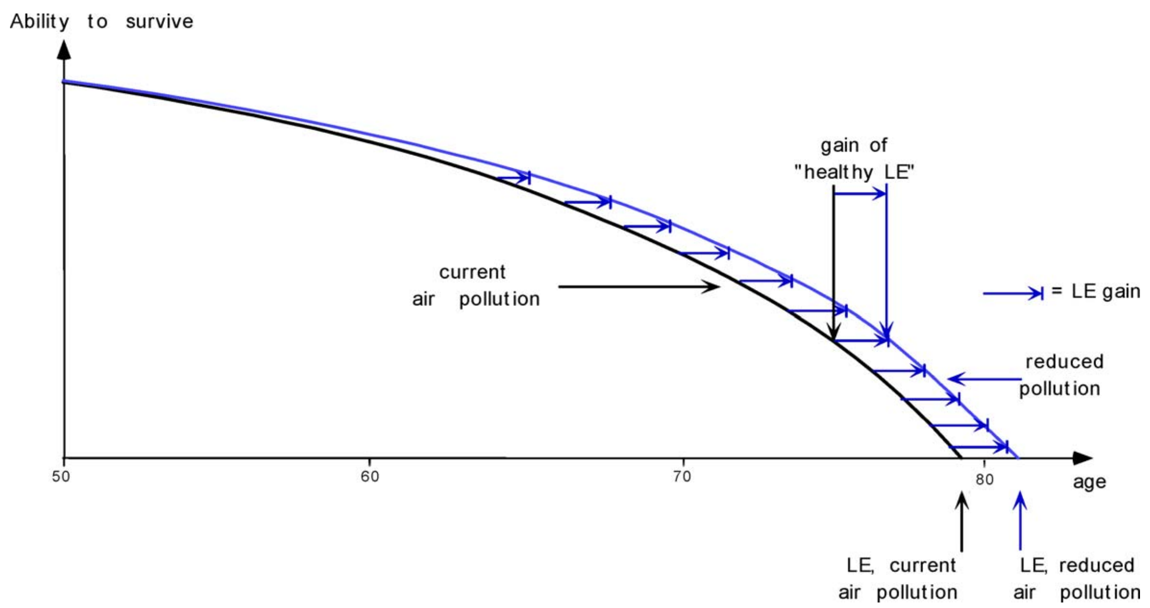

Fig. 1. Gain of life expectancy (LE) when air pollution is reduced. The graph was adapted for different age groups; this example is for someone who was age 50 now.

ble impacts. The impacts are multiplied by the corresponding costs and all is summed over receptors and impacts, to obtain, for example, the damage cost due to a ton of SO_2 emitted by a given power plant. Many studies have quantified the damage costs of air pollution and found that premature mortality makes by far the largest contribution (ORNL/RFF, 1994; Rowe et al., 1995; ExternE, 1998; ExternE, 2005; Levy et al., 1999; Abt, 2004; NRC, 2009, and others). The present paper provides a key element for this work, namely the monetary valuation of air pollution mortality.

Whereas all studies before 1996 calculated a number of premature deaths due to air pollution and multiplied it by the value of prevented fatality (VPF).[1] there has been a growing recognition in recent years that it is also meaningful to look at change of life expectancy (LE) and use VOLY (value of a life year) to calculate the cost; see for instance Wilson and Crouch (2001) for the relevance of LE change, and Hammitt (2007) and Brunekreef et al. (2007) for the choice between VPF or VOLY for the valuation. Nonetheless some agencies, e.g. the US Environmental Protection Agency continue to use number of deaths as the impact indicator and basis for monetary valuation; whereas DG Environment of the European Commission uses both the VPF and VOLY approaches; see e.g. the Clean Air For Europe program (Holland et al., 2005).

There are several reasons why number of deaths is not appropriate for the total mortality impact of air pollution, the first two being obvious, the third and fourth having been explained by Rabl (2003) (see also Miller and Hurley, 2003):

(i) Air pollution cannot be identified as a primary cause of an individual death and is only a contributing cause; one cannot simply add the number of deaths due to causes (such as smoking, unhealthy food or lack of exercise) that contribute to several different deaths because one would end up with numbers far in excess of total mortality.
(ii) The number of deaths approach fails to take into account that the magnitude of the loss of LE per death is very much shorter for premature deaths due to air pollution (population average less than a year in Europe and North America (Rabl, 2003)) than for fatal accidents (LE loss typically 30–40 years), on which VPF estimates are based.
(iii) By contrast to primary causes of death, such as fatal accidents, the total number of premature deaths attributable to air pollution is not observable. This is partly due to the fact that the studies that measure the total impact (e.g. Pope et al., 2002) cannot distinguish between whether the result is due to some individuals suffering a large LE loss per death or everybody loosing a little. In the latter case every premature death would be an "air pollution death", regardless of the pollution level.
(iv) The method that has been used for calculating the number of deaths (for epidemiological studies of the cohort type) is wrong because it does not take into account the corresponding change in the age structure of the population.

The LE change approach avoids these problems,[2] because the population-averaged LE change can be determined unambiguously. It is a meaningful and appropriate impact indicator for all risk factors, even those that are not observable as the cause of an individual death. Moreover, for small risk changes it can be added across different risk factors.

Therefore one needs data for VOLY. However, as opposed to the numerous VPF studies, VOLY has attracted very little attention until recently, and reliable information is still lacking. One possible approach, used in ExternE (1998), is to determine VOLY from VPF by assuming that the latter is the present value of the sum of the VOLYs for the remaining life years, with due consideration of discount rate and survival probabilities. However, such an approach is problematic for several reasons, including the very different nature of the deaths. VPF is based on accidental deaths, whereas VOLY is for a shift in the timing of death without a significant change in the nature of the death (the case of air pollution). An analysis of

[1] The traditional term "value of statistical life" (VSL) is unfortunate, because it tends to evoke hostile reactions by non-economists, However, people tend to accept the concept if it is presented as the "willingness-to-pay for avoiding an anonymous premature death", i.e. the value of preventing a fatality (VPF).

[2] The above points concern adult mortality. For infant mortality, the issues are quite different, with respect to both epidemiology and monetary valuation. The number of infant deaths due to air pollution can be determined, and the LE loss can be very large since many individuals who were extremely frail and close to death during infancy go on to live a full life span. However, even if one assumes a loss of 80 life-years per infant death, this makes up a very small contribution to the total LE loss due to air pollution. Thus, we do not address this issue in this paper.

Table 1
Statistics of survey sample and of general population.

	Survey sample statistics			National statistics (2002)		
Country	Respondents	% Female	Net income (k€/year, PPP)	Population (millions)	Income per capita (k€/year)	% Female
Switzerland	179	51	30.8	7	34.6	50
Czech Rep.	229	47	10.5	10	5.2	51
Germany	300	51	18.8	82	25.5	51
Denmark	136	50	19.4	5	28.9	51
Spain	100	52	17.6	41	13.9	51
France	101	57	18.0	60	21.3	51
Hungary	118	62	8.8	10	5.1	52
Poland	150	53	9.4	39	4.4	51
UK	150	51	24.3	59	24.4	51

life extending consumer purchases, such as dietary supplements, does not look promising because of the lack of information on the associated LE gains.

Thus the most appropriate method for determining VOLY is Stated Preference approaches like Contingent Valuation (CV). This paper reports the first multi-country application of CV to estimate VOLY directly. Our CV questionnaire was designed specifically for air pollution mortality and tested thoroughly in focus groups and pre-tests. To estimate VOLY, respondents were asked their willingness-to-pay (WTP) for LE gains of 3 and 6 months achieved by corresponding air pollution reductions under realistic policy scenarios. The survey was administered in face-to-face interviews to a representative sample of the population in one major city in each of the 9 countries of the EU: Newcastle upon Tyne (UK), Paris (France), Warsaw (Poland), Prague (Czech Republic), Budapest (Hungary), Karlsruhe (Germany), Neuchâtel (Switzerland), Barcelona (Spain) and Copenhagen (Denmark). The total number of respondents was 1463 aged between 20 and 75.

2. State-of-the-art of CV for VOLY

The first survey that asked explicitly about the valuation of an LE gain is the one of Johannesson and Johansson (1996, 1997) (administered by telephone to 2824 individuals), whose valuation question was: "*The chance for a man/woman of your age to become at least 75 years old is x percent. On average, a 75-year old lives for another 10 years. Assume that if you survive to the age of 75 years you are given the possibility to undergo a medical treatment. The treatment is expected to increase your expected remaining length of life to 11 years. Would you choose to buy this treatment if it costs y and has to be paid for this year?*" The resulting VOLY values are very low, in the range of $700 to $1300. However, as noted by the authors, there are many factors that could explain such low values; especially the expected quality of life at an old age which was asked explicitly. Another reason for the observed low VOLY could be the mode of payment, which was a one-time payment rather than a flow of annual (or monthly) payments. Half of the sample had zero WTP. Even looking at only those that were willing to pay something results in a VOLY of $2700, which still seems to be a very low value.

In Morris and Hammitt (2001), the CV question asked for WTP for a hypothetical pneumonia vaccine. Half of the sample (n = 332) received a version in which the benefit was expressed as LE gain and for the other half (n = 349) the benefit was expressed as a reduction of the risk of dying. Each sample was then split in two. The first group was asked about their WTP for a vaccine received at the age of 60 (LE = 11 months), while the second group was asked for their WTP for a vaccine received at the age of 70 (LE = 5 months). Interviews were made by phone after respondents received a mailed packet of information material. The mean age of the sample was 40 years. 30% of the sample would not take the vaccine, mainly because the benefits are too small or uncertain. The results show that if benefits are expressed in terms of LE gain, the median WTP is 52% higher than for the risk reduction for a vaccine at 60 (but equal for a vaccine at 70). The authors conclude that LE is more readily understandable and enhances the validity of economic valuation.

Soguel and van Griethuysen (2000) determined a VOLY related to air pollution, albeit somewhat indirectly. A representative sample of the city of Lausanne (n = 199) were asked in-person to value a bundle of health damages caused, each year, by an incinerator: 6000 days of life lost, 1200 cases of restricted activity days and 500 new cases of chronic bronchitis and asthma. Expressed as average loss per person, this is 1 h of life per year, a 1% chance to have a restricted activity day, and 0.5% chance to suffer from chronic bronchitis. The ranking enabled the authors to apportion the WTPs among the different health outcomes and to extract an implicit VOLY. They obtained a VOLY of 53,000 Swiss Francs (34,000 €) based on a Box-Cox regression.

In the late 90s Krupnick and his colleagues at Resources for the Future developed a self administered and computerized CV questionnaire to value specifically the benefits of air pollution reduction. It was first applied in Canada (Krupnick et al., 2002), and then in USA (Alberini et al., 2004a). The respondents were asked to value 1 in 1000 and 5 in 1000 reductions in their risk of dying during the next 10 years, as well as at the age of 70. These risk reductions for

Table 2
Responses to the question: "Are you aware that your consumption and lifestyle contribute to air pollution?".

Countries	No	Yes	I know but do not think about it	Missing
Switzerland	2%	87%	12%	0%
Czech Republic	9%	70%	20%	1%
Germany	6%	80%	14%	0%
Denmark	10%	90%	0%	0%
Spain	41%	52%	7%	0%
France	4%	78%	18%	0%
Hungary	8%	90%	0%	3%
Poland	13%	84%	3%	0%
UK	13%	97%	0%	0%
Pooled data	9%	81%	10%	0%

Table 3
Distribution (in %) of answers to the question: "Are you willing to accept a higher cost of living, therefore an increase in your daily expenses, to gain an increase in your life expectancy?" (see text for definition of the reply options 1–8).

Countries	1	2 protest	3	4	5 protest	6	7	8	Missing
Switzerland	70	8	5	3	7	5	2	0	0
Czech Rep.	80	7	4	1	0	5	0	0	2
Germany	74	11	6	3	3	3	0	0	0
Denmark	96	0	3	1	0	1	0	0	0
Spain	50	7	10	11	15	7	0	0	0
France	77	6	8	4	4	1	0	0	0
Hungary	71	6	14	3	5	2	0	0	0
Poland	63	11	13	5	3	1	3	1	0
UK	93	0	0	1	1	2	0	0	3
Pooled data	76	7	7	3	4	3	1	0	1

Table 4
Analysis of protest responses (for 3 month LE gain).

Countries	Sample (N)	WTP = 0 (% of total)	Protest (% of WTP = 0)	WTP = 0 (% of total, protest removed)
Switzerland	179	31	49	18
Czech Republic	229	19	34	14
Germany	300	29	48	17
Denmark	136	4	0	4
Spain	100	53	42	40
France	101	35	29	27
Hungary	118	31	35	23
Poland	150	38	39	27
UK	150	7	18	6
Pooled data	1463	26	39	18

a 10 year period correspond to annual risk reductions of 1 in 10, 1000 and 5 in 10,000, respectively. The payment vehicle is a medical product to be taken for 10 years. The sample is composed of persons from 40 to 75 years old. For Canada the authors derive a VPF of $0.96 million for a 5 in 10,000 annual risk reduction, and of $3.04 million for a 1 in 10,000 annual risk reduction.

Even though Krupnick et al. did not try to determine VOLY, their CV survey was used for that purpose by Alberini et al. (2004b) within the NewExt phase of the ExternE project series of the EU DG Research (see www.externe.info). The CV survey was applied to estimate VPF in the UK, Italy and France, and then VOLY was derived from this VPF figure. A VOLY of 50,000 € was recommended for the EU15. The French survey (Desaigues et al., 2007a), as opposed to those in Italy and the UK, involved several additional features including an open question asked after each set of bids, and at the end of the questionnaire the WTP values were recalled to give the respondents the opportunity to correct their values. Five versions were tested in subsamples of about 50 respondents each, including versions phrased explicitly in terms of LE gain. Each in-person interview was followed by debriefing questions, and for some versions also an open debriefing interview was conducted in order to learn how the respondents interpreted the questions. The experience from the NewExt project led to the decision to develop a new VOLY CV survey for the NEEDS phase of ExternE.

Chilton et al. (2004) conducted a CV survey in the UK between November 2002 and January 2003. Like the Swiss study by Soguel and van Griethuysen (2000) respondents were asked to value a bundle of damages related to a reduction in air pollution. 665 persons were asked to value a LE gain of one, three, or six months in normal health (and the same in poor health), as well as avoiding hospital admission, and avoiding breathing discomfort. The VOLY in normal health is 27,639 £ (42,000 €) for the one month sample, 9430 £ (15,000 €) for the three months sample, and 6040 £ (10,000 €) for the six months sample. Note that VOLY decreases with larger LE gain, since the WTP of the respondents does not increase proportionally with the size of the LE gain. This could be explained by the fact that their budget constraint becomes more limiting as the LE gain increases. The VOLY in poor health is much lower than for perfect health. More than half of the sample stated zero WTP for a LE gain in poor health, with the estimate VOLY ranging from 7280 £ for the one month subsample, to 1290 £ for the six month subsample. This clearly shows that people value a gain in LE less when they are in poor health during the gained period compared to being in normal health.

3. Survey questionnaire

The final questionnaire and CV scenario were constructed based on extensive testing of previous versions. Pre-tests in each country found that some formulations had to be modified to avoid misunderstandings in the different cultural and linguistic contexts of these nine different countries. When necessary we opted for freer rather than literal translations to national languages (from English) in order to convey the same meaning and CV scenarios. The questionnaire started by telling the respondent that our study is funded by the European Union, with the objective to find out how much he/she values an LE gain if air pollution is reduced. Then the respondents were asked to consider the effect of pollution on their health and whether it was of general concern to them. The respondents were given information on average life expectancy in the various countries and how air pollution affects LE. Attention was also drawn to his/her own LE, given their age and factors which affect individual LE such as genetic, behavioral and environmental conditions.

To introduce the valuation question, we describe two potential policies A and B that would reduce air pollution and hence generate LE gains: “Policy A will impose a 3% reduction per year in the emission of air pollutants for 20 years, for a total reduction of 60% by 2025. Afterwards the emission of air pollutants will be maintained at this lower level whatever the economic growth. The benefit in terms of life expectancy would be an average increase of 6 months”. Policy B involves an analogous 1.5% reduction of annual emissions, for a total of 30% by 2025, and an LE gain of 3 months. The order in which respondents was asked for a 3 and 6 months gain in LE was varied at random.

Great care was taken to explain the nature of the LE gain, in particular that it is not a matter of additional months of misery at the end of one's life. Rather pollution causes accelerated aging. For this purpose we developed a figure (see Fig. 1) which was shown to the respondents to illustrate the ability to survive as a function of age and pollution level. “Ability to survive” is used only as a qualitative concept, without any need for a quantitative definition. The figure shows the ability to survive as function of age, for two different levels of air pollution. If the level of air pollution decreases (increases), the survival curve will expand (shrink) in the horizontal direction. LE gains arise as small increases in the probability of survival throughout life due to a slowing of the aging process. It was also emphasized that while most of the risk reduction (or increased chance of survival) occurs towards the end of a person's life, conditional on reaching this stage, some benefit occurs immediately.

Since an expansion of the “ability to survive” curve implies, at any given age, an improvement of health and thus of quality of life, the concept of VOLY involves also a change in the quality of life before death. That is intrinsic in any meaningful definition of VOLY. Whatever the shape of the curves in Fig. 1, at any given age an LE gain implies an upward shift of the “ability to survive” curve, at least near the end of the curve. The only exception would be an unrealistic scenario where the curve is extended just along the horizontal axis (and the entire LE gain would be lived hovering at the threshold of death). All the evidence on the effects of air pollution (just like for smoking) indicates that accelerated aging is a good way of describing the effects, and thus Fig. 1 is appropriate.

Then the interviewer explained that the cost of any measures to reduce air pollution would increase prices and hence the cost of living. The respondents were asked first of all whether they would in principle be willing to pay something in the form of higher prices to gain an increase in their life expectancy.

If the response to this question was 'no', respondents were asked the reasons for their zero WTP. This was done in order to distinguish "protest zeros" from "real zeros". "Protest zeros" state a zero WTP to protest some aspect of the CV scenario, e.g. saying that they do not think prices should increase or that the government and/or polluting firms should pay for reductions in air pollution rather than households. Thus, they probably have a positive WTP, and by counting them as zero we would underestimate the real WTP. Thus, protest zeros are excluded from the sample and only the real zeros and those with positive WTP are used when calculating mean WTP Those who said 'yes' to paying were reminded of their budget constraint, and then asked to state their maximum WTP for the six month gain in average life expectancy followed by the three month gain (or the reverse order). To help respondents determining their maximum WTP, they were given a set of cards, each with a different amount, and a template. They were asked to shuffle the cards, draw one card and decide if they were willing to pay that amount per month for the rest of their lives or not. If "yes" they were told to place it on the template in the box marked "definitely would pay". If "no", they were told to place it in the box marked "definitely would not pay". If they were not sure, they were asked to place it in the "unsure" box. The participant repeated this exercise for all cards/amounts. The interviewer recorded the highest value placed in the "definitely would pay" box along with the lowest value placed in the "definitely would not pay" box. The interviewer then proceeded to ask the participant the *highest* amount they would be willing to pay for the given increase in life expectancy.

Additional questions were asked to help us understand the responses and remove protest zeros and outliers, as discussed in the following section. The complete questionnaire as well as additional detail can be found in the Annex of the full report (Desaigues et al., 2007b).

4. Survey results

4.1. Characteristics of the respondents

Table 1 reports the results from a comparison of our sample with the national population statistics to test the representativeness of our sample. While the sample cannot claim to be representative of the individual countries, the differences are not unreasonably large. Remember that the sample was recruited from a large city in each country, as the air pollution scenario is most realistic in big cities and our survey budget was limited (and in-person interviews as the preferred survey mode in CV surveys are costly). Thus, our sample was not recruited to be representative of the country but of the individual cities. However, to use the resulting VOLY values in cost–benefit analysis at the EU-level, the value is implicitly assumed to representative of the overall adult population.

Note that for improved readability we have rounded numbers in the tables throughout this paper; thus totals may not always add to 100%.

Table 2 shows that across the sample there is a high degree of awareness that the respondents' own actions contribute to the air pollution problem. Only the Spanish sample appears not to be well-versed in the linkage.

4.2. WTP results

To identify protest and real zeros, we asked "Are you willing to accept a higher cost of living, therefore an increase in your daily expenses, to gain an increase in your life expectancy?", with the following reply options:

1) yes
2) no, refuses scenario (link of pollution and LE, payment vehicle, do not trust institutions)
3) no, budget constraint (cannot pay for anything extra, no purchase power)
4) no, not interested in living longer (too old to benefit, not concerned with LE)
5) no, someone/something else should pay (industries, companies, etc.)
6) no, 3/6 months is too short
7) no, only interested in pollution reduction
8) no, no specified reason.

Table 5
Monthly WTP for 3 months life expectancy gain, excluding protest responses (€/month, Purchase Power Parity (PPP) adjusted).

Countries	Sample (N)	Median (€)	Mean (€)
Switzerland	148	12.42	27.22
Czech Rep.	213	8.98	27.82
Germany	254	21.52	37.86
Denmark	134	22.62	41.86
Spain	78	11.1	25.39
France	91	9.37	22.49
Hungary	105	3.38	14.18
Poland	128	8.56	18.48
UK	148	10.91	21.53
Pooled data	1299	11.95	27.91

The responses to this question are summarized in Table 3. Among respondents with zero WTP, the most frequent reasons are the budget constraint (7%) and refusal of the scenario (7%). We judge that answers 2 and 5 signify protest bids (11% of the total) and we use this classification in the subsequent analysis of WTP.

The distribution of real zeros and protest zeros (i.e. reply options 2 and 5) is shown in Table 4.

The WTP data, based on the highest amount each respondent was willing to pay including real zeros but excluding protest zeros, were analyzed. Table 5 reports the mean and median WTP per person per month for a 3 month LE gain. As in most CV surveys, the mean WTPs are much higher than the medians because the distribution is skewed, reflecting the fact that there are many zeros and some respondents with very high WTP.

Table 6 shows the results of both the 3-month and 6-month WTP questions after removing outliers (defined as an amount that seems to be unrealistically high given the budget constraint of the respondent). The results show that WTP does not increase proportionally with the increase in LE gain. Thus, for the pooled sample the 6 month/3 month ratio is 1.3 rather than 2. A subsequent question about the reasons for the lack of proportionality showed that there was significant variation between countries in terms of the dominant reason stated. However, overall the main reason was that the respondents did not see much difference in an LE gain of 6 versus 3 months.

To test how certain respondents were about their stated WTP we asked "Are you confident of the amount you stated you were willing to pay to increase your life expectancy?" As shown in Table 7 the majority of respondents are confident of their WTP bids, lending some support to the belief that these can be interpreted as their "true" WTP. However, the ultimate test would be to try to collect their stated WTP; see e.g. Veisten and Navrud (2006) for an example of such a comparison of actual versus hypothetical WTP in a CV survey.

Table 6
Comparison of Mean WTP for 3 and 6 month LE gains (€/month Purchase Power Parity (PPP) adjusted).

Country	6 month LE gain		3 month LE gain		
	Protesters deleted	Protesters and outliers deleted	Protesters deleted	Protesters and outliers deleted	Ratio 6 month/3 month
Switzerland	32.6	29.3	27.2	23.7	1.2
Czech Rep.	35.8	35.8	27.8	27.8	1.3
Germany	50.0	39.3	37.9	30.2	1.3
Denmark	46.5	37.8	41.9	33.7	1.1
Spain	32.4	27.4	25.4	22.8	1.2
France	34.0	34.0	22.5	22.5	1.5
Hungary	19.3	19.3	14.2	14.2	1.4
Poland	25.8	25.8	18.5	18.5	1.4
UK	29.7	27.9	21.5	19.7	1.4
Pooled data	36.0	32.0	27.9	24.7	1.3

Table 7
Responses to: "Are you confident in your WTP answer?".

Countries	Yes	No	Missing
Switzerland	64%	5%	31%
Czech Republic	83%	7%	9%
Germany	60%	15%	26%
Denmark	82%	17%	1%
Spain	1%	49%	50%
France	65%	35%	0%
Hungary	72%	0%	28%
Poland	57%	6%	37%
UK	79%	14%	7%
Pooled data	65%	14%	21%

To help interpret the WTP bids we also asked the respondents: "When you picked an amount, what did you think about the most?" The reply options offered were:

1) only about your life expectancy
2) cleaner air and its overall benefits on health (I will breathe better, will be in better health)
3) a bit of both
4) other.

The responses are summarized in Table 8. While overall the most frequent explanation was that respondents were thinking of cleaner air as well as all the health benefits (26% of the pooled sample) there was a diverse pattern of responses across countries. Thus, while the most popular answer in Spain was "only life expectancy", in France and Switzerland it was "cleaner air and its overall benefits on health", in Hungary it was "a bit of both" and in the Czech Republic it was "other". Only 11% of the total valued the LE gain alone. However, even if this result indicates that the stated WTP is an overestimate for increased life expectancy, it may well be that this very question made the respondents uncertain about what they had actually been asked to value and led them to state that they considered not only the life expectancy even if they actually had done so.

Table 8
Distribution (in %) of responses to the follow-up question to their stated WTP: "What did you think about most in stating your WTP?" (see text for definition of the response options 1–4).

Countries	1	2	3	4	Missing
Switzerland	6%	41%	24%	0%	30%
Czech Republic	19%	23%	9%	44%	5%
Germany	7%	21%	34%	12%	26%
Denmark	4%	29%	13%	8%	46%
Spain	61%	0%	26%	11%	2%
France	0%	52%	21%	2%	25%
Hungary	3%	20%	44%	4%	28%
Poland	3%	25%	29%	6%	37%
UK	8%	25%	29%	31%	7%
Pooled data	11%	26%	25%	15%	23%

4.3. WTP regression model

As a validity test we regressed the WTP of the pooled sample on income and other characteristics of the respondents. We used a simple model defined as:

$$\mathrm{WTP} = \alpha + x_i \cdot \beta + \varepsilon$$

where ε is the error term, x_i is a $1 \times k$ vector of individual characteristics for individual i and β is a $k \times 1$ vector of unknown parameters. The results are presented in Table 9. Income had a significant positive effect on WTP, as expected from economic theory. If respondents stated concern about health effects of air pollution, they also had significantly higher WTP than those who did not. Those who were sure about their stated WTP also gave significantly higher WTP than those who were not. WTP was also significantly higher for male respondents, and those with the highest education. Age, however, had no significant effect.[3] Overall the WTP regression model seems to perform well, and confirms the validity of our survey although the model has low explanatory power as commonly found for CV surveys.

4.4. Income elasticity of WTP

We also estimated the income elasticity of WTP by using a simple double-log (in WTP and income) model while controlling for the significant individual characteristics observed in the WTP regression model reported in Table 9. The resulting income elasticity of WTP for the pooled sample is between 0.38 and 0.69 (depending on the specification of the model). There are large variations of the elasticity between different countries, with the Central and Eastern European Countries with the lowest income level having the highest income elasticity of WTP.

5. VOLY calculation and discussion

5.1. Calculation of VOLY

We used the WTP figures of Table 6 to estimate the value of a life year according to two slightly different equations (with zero

[3] With regards to the age dependence of VOLY and VPF conflicting (and sometimes ethically controversial) results have been reported in the literature. Two effects tend to draw in opposite directions: On the one hand most people expect reduced income during retirement (which lowers the WTP of older respondents), but on the other hand older people are more conscious of the limited time they have left and the LE gain appears more important.

Table 9
WTP regression model for the pooled data for all nine countries. Protest zeros and outliers have been excluded.

Covariates	6 month LE gain		3 month LE gain	
	Coefficient	Robust standard error	Coefficient	Robust standard error
Constant	−16.53	16.28	−18.23	14.92
Physically bothered by air pollution	1.83	1.58	1.66	1.44
Concerned about health effects of air pollution	3.57**	1.46	2.81**	1.29
Aware that lifestyle contributes to air pollution	−0.84	2.66	−1.15	2.14
Knows that air pollution is harmful to health	3.26	3.05	4.01	2.60
Subjective health status of respondent (1 = good; 2 = average; 3 = poor health)	−0.37	2.58	−1.36	2.20
Has bronchitis and/or asthma	−3.59	3.84	−0.49	3.36
Has emphysema, cancer, cardiovascular or other serious diseases	4.04	4.72	5.61	3.91
Smoker	4.57*	2.71	3.87*	2.33
Sure about stated WTP figures	8.30***	2.93	8.23***	2.53
Has private health insurance	3.72	2.73	2.43	2.39
Male	6.79**	2.76	6.75***	2.48
Superior education level	6.67**	3.26	2.39	2.77
Age	0.66	0.68	0.58	0.57
Age square	−0.01	0.01	−0.01	0.01
Income	0.004***	0.001	0.004***	0.001
N	992	986		
R-square	0.0634	0.0653		

* Significant at the 10% level.
** Significant at the 5% level.
*** Significant at the 1% level.

discount rate as discussed below). The first uses the life expectancy LE_k and average age of the sample in each country k

$$\begin{aligned}\mathrm{VOLY}_k &= (\mathrm{WTP}_{3,k} \times 12) \times 4 \times (\mathrm{LE}_k - \text{average age of sample}_k)\\ \mathrm{VOLY}_k &= (\mathrm{WTP}_{6,k} \times 12) \times 2 \times (\mathrm{LE}_k - \text{average age of sample}_k)\end{aligned} \quad (1)$$

where $\mathrm{WTP}_{3,k}$ and $\mathrm{WTP}_{6,k}$ are the average monthly WTPs in country k, for 3 and 6 months, respectively. Alternatively, we have used the remaining life expectancy $\Delta\mathrm{LE}_{k,\mathrm{i}}$ of each individual i (calculated by means of the life tables of each country k according to the gender and age of respondent i)

$$\begin{aligned}\mathrm{VOLY}_k &= \frac{1}{n_k}\sum_{i=1}^{n_k}(\mathrm{WTP}_{3,k,i} \times 12) \times 4 \times \Delta\mathrm{LE}_{k,i}\\ \mathrm{VOLY}_k &= \frac{1}{n_k}\sum_{i=1}^{n_k}(WTP_{6,k,i} \times 12) \times 2 \times \Delta LE_{k,i}\end{aligned} \quad (2)$$

where n_k = number of respondents in country k. In order to account for differences in population size among the 9 countries in our sample we re-estimated the pooled countries VOLY weighted by the populations in the New Member Countries (NMC) and the EU15 + Switzerland countries (“EU16”). In mathematical form:

$$\mathrm{VOLY}_{\mathrm{POOLED\text{-}WEIGHTED}} = \frac{(\mathrm{VOLY}_{\mathrm{NMC}} \times \mathrm{POP}_{\mathrm{NMC}}) + (\mathrm{VOLY}_{\mathrm{EU16}} \times \mathrm{POP}_{\mathrm{EU16}})}{\mathrm{POP}_{\mathrm{NMC}} + \mathrm{POP}_{\mathrm{EU16}}} \quad (3)$$

The results of these calculations can be seen in Table 10. It turns out that the differences between Eqs. (1) and (2) are small compared to the overall uncertainties.

5.2. Discounting

The choice of the appropriate discount rate for the calculation of VOLY has to consider how the respondents perceived the payments. Did they see a future payment as having the same nominal value as one made today, or did they implicitly discount the future? In the latter case no further discounting should be applied. By emphasizing that the payments must be made for the entire remaining life time we obliged the respondents to think about the future of the payment series. Therefore we believe that their reported WTP are implicitly discounted. However, future CV surveys of VOLY should include questions asking respondents whether they apply some sort of discounting when reporting their monthly WTP for the remaining lifetime to test this assumption.

5.3. Mean versus median

As in most CV surveys, mean WTP is much higher than the median WTP. One could argue for using the median WTP in calculating VOLY because it is less sensitive to respondents stating very high WTP which are not representative or realistic, and thus would have a large effect on mean WTP especially in small samples. The median is in effect a voting system where the WTP of each individual is counted only as being above or below a reference value, i.e. the median; that is analogous to typical yes/no choices in democratic elections. By contrast, the mean takes the strength of the vote into account. An individual A whose WTP is twice that of individual B carries twice as much weight in calculating the mean WTP. We argue that the strength of the vote should be taken into account for issues that clearly involve a matter of degree. Determining a VOLY for environmental policy is a matter of degree, not a simple yes/no, and thus it seems more appropriate to take the strength of each vote into account by using the mean (Note, however, that we use only means where the outliers have been removed).

Calculating VOLY from mean WTP is also in accordance with economic welfare theory, which is the theoretical basis for cost–benefit analysis (e.g. of new regulatory policies for air pollution) where VOLY estimates typically would be used.

5.4. VOLY and the size of the life expectancy gain

One of the problems with CV of mortality is the dependence of the resulting VOLY (or VPF) on the magnitude of the LE gain (or of the risk reduction) that is described in the elicitation question (see e.g. Braathen et al., 2009). Typically the WTP increases far less than the proposed benefit. This lack of strict proportionality (often termed “not passing the scope test) is notorious in CV studies (see e.g. Beattie et al., 1998). Is the phenomenon a cognitive illusion or a correct valuation? It could be the latter due to nonlinearities of the utility function. Such nonlinearities can arise from diminishing marginal utility or from budget constraints. Diminishing marginal utility of LE gains does not appear rational in view of the almost universal desire to live as long as possible. But budget constraints may set in fairly soon: at 40,000 €/VOLY how many years do people think they can afford to buy?

Another reason for the lack of proportionality may lie in the possibility that people perceive the magnitude of their WTPs on a

Table 10
Population-weighted VOLY (Purchase Power Parity (PPP) adjusted €). Protest zeros and outliers are excluded. A comparison of Eqs. (1) and (2) with the population weighted VOLY from Eq. (3).

Method	"EU16"[a]	NMC[a]	Population-weighted pooled, Eq. (3)
For 6 month LE gain			
Mean as in Eq. (1)	25,762	19,339	24,733
Mean as in Eq. (2)	27,863	24,525	27,328
Median as in Eq. (1)	16,989	5984	15,226
Median as in Eq. (2)	16,778	8105	15,389
For 3 month LE gain			
Mean as in Eq. (1)	40,133	29,228	38,386
Mean as in Eq. (2)	42,548	37,309	41,709
Mean, averaged over Eqs. (1) and (2)	41,341	33,269	40,048
Median as in Eq. (1)	20,886	11,409	19,368
Median as in Eq. (2)	22,921	11,174	21,039
Population (million)			
	388 (EU15)	74 (EU25-EU15)	462 (EU25)

[a] "EU16" = EU15 + Switzerland, NMC = New Member Countries (Czech Rep, Hungary and Poland).

logarithmic rather than linear scale. Logarithmic scales of perception are a well established fact for several senses, especially vision and hearing (e.g. http://en.wikipedia.org/wiki/Dynamic_range), and they are a necessity if sufficient sensitivity to changes is to be achieved over a very large range of stimuli. It seems plausible that the perception of monetary amounts, or other quantities, may also be more logarithmic than linear. For example a change from one million to two million may not appear much larger than a change from one hundred thousand to two hundred thousand if such changes are perceived more in relative than in absolute terms. Perception in relative terms may be especially likely when the good in question is not at all familiar.

We do not know to what extent the lack of proportionality between 3 and 6 months is due to budget constraints or to non-linear perception. Whatever the cause, the effect is awkward for the determination of VOLY: one can obtain a wide range of different VPF or VOLY results, depending the gain described in the elicitation question.

In this context one should not forget the needs of policy makers; after all, it is for their cost–benefit analyses of regulatory policies that studies of VPF and VOLY are carried out. The purpose is to provide a basis for more rational and consistent decision making about life saving measures. To see what could happen if VOLY decreases with LE gain, suppose that two independent policy options A and B each bring a small LE gain with sufficiently high VOLY to pass the cost–benefit criterion, so they will both be recommended for implementation. Thus, it is in effect the combined package C = A + B that is recommended. But suppose further that VOLY for the LE gain of the combined package C is too low because of those diminishing returns. What should policy makers do? The only way to avoid this kind of inconsistency is to use a single VOLY, for the entire range of LE gains that might be under consideration.

To find the appropriate single value we argue that Policy A of our CV survey the one with the 3 month LE gain, is particularly realistic whereas Policy B, with the 6 month gain, is quite ambitious. If the lack of proportionality is due to nonlinear perception, this would also support the estimation of VOLY based on the 3 month LE gain.

6. Conclusion

The main findings of our 9-country European Contingent Valuation (CV) survey of Willingness-to-Pay (WTP) for a Life Expectancy (LE) gain of 3 and 6 months due to reduced air pollution to establish an European Value of a Life Year (VOLY) are:

(i) The mean WTP is more than twice as high as the median WTP. Mean WTP is the welfare theoretic correct measure.

(ii) For the pooled sample of all 9 countries, 39% of those who stated zero WTP are classified as protest zeros, i.e. they have a positive WTP but state zero because they protest one or more aspects of the CV scenario. We have excluded these protest zero answers from the sample before calculating mean and median WTP and the corresponding VOLY.

(iii) The outliers (here defined as those that accepted the highest bid on the payment card in each country) were only 15 and 13 persons for 3 and 6 months LE gain, respectively. Thus, they constitute less than 1.5% of the sample, but deleting them reduces the mean VOLY by 11–13%. The highest bid on the payment card implies a monthly WTP of about 250 €, and an annual WTP of 3000 €, which was unrealistically high compared to disposable income for almost everyone in the sample. Even though we cannot exclude the possibility that a small part of the European population has such a high WTP, this proportion is probably overestimated in our sample. In order not to overestimate VOLY, we have excluded these "outliers" from our VOLY calculation.

(iv) The sample size for each country is too small to provide reliable country estimates of VOLY. However, the pooled sample from all 9 countries, and the estimates for "EU16" (i.e. EU15 + Switzerland, the EU15 represented here by Denmark, Spain, France, Germany and the UK) and NMC (i.e. New Member Countries, represented here by the Czech Republic, Hungary and Poland) are large enough to produce representative estimates of VOLY.

(v) The VOLY estimates based on WTP for a 3-month LE gain are significantly higher than those based on WTP for 6 months LE. For the pooled sample the ratio of WTP for 6 months/WTP for 3 months is 1.3. Because individuals' budget constraint will kick in for the 6-month LE, we recommend using the mean VOLY estimate based on the WTP for a 3-month LE gain.

Based on this, our recommended **VOLY** estimates are

EU15 + Switzerland: 41,000 €
New Member Countries: 33,000 €

For application in cost–benefit analyses of new EU directives and policies we recommend using the same value for all countries within the European Union, using the VOLY of the pooled sample. With adjustments to correct for the difference in the proportion of EU15 and NMC observations in our sample and the actual populations we recommend an EU-wide VOLY of 40,000 €. As for confidence intervals, we argue that VOLY is at least 25,000€ and at the most 100,000€.

Acknowledgment

We thank Anna Alberini for helpful comments.

Role of the funding source: This work has been funded by the NEEDS (New Energy Externalities Developments for Sustainability) project of the ExternE series of the European Commission DG Research. Additional funding for the German survey was provided by Electricité de France (EDF). The funding sources had no influence on the design or execution of the study nor on the publication of this paper.

References

Abt, 2004. Power Plant Emissions: Particulate Matter-Related Health Damages and the Benefits of Alternative Emission Reduction Scenarios. Prepared for EPA by Abt Associates Inc., 4800 Montgomery Lane, Bethesda, MD 20814-5341.

Alberini, A., Cropper, M., Krupnick, A., Simon, N.S., 2004a. Does the value of a statistical life vary with age and health status? Evidence from US and Canada. Journal of Environmental Economics and Management 48, 769–792.

Alberini, A., Hunt A., Markandya, A., 2004b. Willingness to Pay to Reduce Mortality Risks: Evidence from a Three-country Contingent Valuation Study. Paper Submitted for Presentation at the Annual EAERE Meeting, Budapest, 25–28 June, 2004.

Beattie, J., Covey, J., Dolan, P., Hopkins, L., Jones-Lee, M., Loomes, G., Pidgeon, N., Robinson, A., Spencer, A., 1998. On the contingent valuation of safety and the safety, of contingent valuation: part 1. Caveat investigator. Journal of Risk and Uncertainty 17, 5–25.

Braathen, N.A., Lindhjem, H., Navrud, S., 2009. Valuing lives saved from environmental, transport and health. OECD report. In: Presented at the conference "Managing the Social Impacts of Change from a Risk Perspective , 15–17.4.2009 Beijing, China.

Brunekreef, B., Miller, B.G., Hurley, J.F., 2007. The brave new world of lives sacrificed and saved, deaths attributed and avoided. Epidemiology 18 (6), 785–788.

Chilton, S., Covey, J., Jones-Lee, M., Loomes, G., Metcalf, H., 2004. Valuation of Health Benefits Associated with Reductions in Air Pollution. Final report. Department for Environment Food and Rural Affairs (DEFRA), May 2004.

Desaigues, B., Rabl, A., Ami, D., Boun My Kene, Masson, S., Salomon, M.-A., Santoni, L., 2007a. Monetary Value of a Life Expectancy Gain due to Reduced Air Pollution: Lessons from a Contingent Valuation in France. Revue d'Economie Politique 117 (5), 675–698.

Desaigues, B., Ami, D., Bartczak, A., Braun-Kohlová, M., Chilton, S., Farreras, V., Hunt, A., Hutchison, M., Jeanrenaud, C., Kaderjak, P., Máca, V., Markiewicz, O., Metcalf, H., Navrud, S., Nielsen, J.S., Ortiz, R., Pellegrini, S., Rabl, A., Riera, R., Scasny, M., Stoeckel, M.-E., Szántó, R., Urban, J., 2007b. Final Report on the Monetary Valuation of Mortality and Morbidity Risks from Air Pollution. Deliverable for WP6 of RS1b of NEEDS Project, July 2007.

ExternE: Externalities of Energy. Vol.7: Methodology 1998 Update (EUR 19083); Vol.8: Global Warming (EUR 18836); Vol. 9: Fuel Cycles for Emerging and End-Use Technologies, Transport and Waste (EUR 18887); Vol.10: National Implementation (EUR 18528). Published by European Commission, Directorate-General XII, Science Research and Development. Office for Official Publications of the European Communities, L-2920 Luxembourg. Results are also available at http://ExternE.jrc.es/publica.html. For updates see www.externe.info.

ExternE – Externalities of Energy: Methodology 2005 Update. Available at http://www.externe.info.

Hammitt, J.K., 2007. Valuing Changes in Mortality Risk: Lives Saved vs. Life Years Saved. Review of Environmental Economics and Policy. Oxford University Press.

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. Journal of Risk and Uncertainty 13, 163–174.

Johannesson, M., Johansson, P.-O., 1997. Quality of life and the WTP for an increased life expectancy at an advanced age. Journal of Public Economics 65, 219–228.

Holland, M., Hunt, A., Hurley, F., Navrud, S., Watkiss, P., 2005. Methodology for the Cost–Benefit Analysis for CAFE: Volume 1: Overview of Methodology. Didcot. UK: AEA Technology Environment. Available: http://europa.eu.int/comm/environment/air/cafe/pdf/cba_methodology_vol1.pdf.

Krupnick, A., Alberini, A., Cropper, M., Simon, N., O'Brien, B., Ron Goeree, R., Heintzelman, M., 2002. Age, Health, and the Willingness to Pay for Mortality Risk Reductions: A Contingent Valuation Survey of Ontario Residents. Journal of Risk and Uncertainty 24 (2), 161–186.

Levy, J.I., Hammitt, J.K., Yanagisawa, Y., Spengler, J.D., 1999. Development of a new damage function model for power plants: methodology and applications. Environmental Science & Technology 33 (24), 4364–4372.

Miller, B.G., Hurley, J.F., 2003. Life table methods for quantitative impact assessments in chronic mortality". Journal of Epidemiology and Community Health 57, 200–206.

Morris, J., Hammitt, J., 2001. Using life expectancy to communicate benefits of health care programs in contingent valuation studies. Medical Decision Making 2001, 468–478.

NRC, 2009. Hidden Costs of Energy: Unpriced Consequences of Energy Production and Use. National Research Council of the National Academies Press. National Academies Press, 500 Fifth Street, NW Washington, DC 20001.

ORNL/RFF, 1994. External Costs and Benefits of Fuel Cycles. Prepared by Oak Ridge National Laboratory and Resources for the Future. Edited by Russell Lee, Oak Ridge National Laboratory, Oak Ridge, TN 37831.

Pope, C.A., Burnett, R.T., Thun, M.J., Calle, E.E., Krewski, D., Ito, K., Thurston, G.D., 2002. Lung cancer, cardiopulmonary mortality, and long term exposure to fine particulate air pollution. Journal of the American Medical Association 287 (9), 1132–1141.

Rabl, A., 2003. Interpretation of air pollution mortality: number of deaths or years of life lost? Journal of the Air & Waste Management Association 53 (1), 41–50.

Rowe, R.D., Lang, C.M., Chestnut, L.G., Latimer, D., Rae, D., Bernow, S.M., White, D., 1995. The New York Electricity Externality Study. Oceana Publications, Dobbs Ferry, New York.

Soguel, N., van Griethuysen, P., 2000. Evaluation contingente, qualité de l'air et santé: une etude en milieu urbain (Contingent valuation, air quality and health: a study in an urban environment). Report IDHEAP 185/2000. Institut des Hautes Etudes en Administration Publique, Université de Lausanne, Lausanne, Switzerland.

Veisten, K., Navrud, S., 2006. Contingent valuation and actual payment for voluntarily provided passive-use values: Assessing the effect of an induced truth-telling mechanism and elicitation formats. Applied Economics 38, 735–756.

Wilson, R., Crouch, E.A.C., 2001. Risk-Benefit Analysis. Harvard University Press, Cambridge, MA.