

Chapter 1. Introduction

16 June 2013

“The responsibility of those who exercise power in a democratic society is not to reflect inflamed public feeling but to help form its understanding”

Felix Frankfurter (former Supreme Court Justice) (1928)

Carved in stone on the wall of the Federal Court House, Boston

1.1. Why Quantify Environmental Benefits?	2
1.2. Costs Are Not the Only Criterion for Decisions	4
1.3. Cost-Effectiveness Analysis	5
1.4. The Optimal Level of Pollution Abatement	7
1.5. How to Quantify Environmental Benefits	9
1.5.1. Impact Pathway Analysis	9
1.5.2. Why Not Simply Ask People How Much They Value Each Impact?	10
1.6. External Costs and their Internalization	11
1.6.1. Definition of External Costs	11
1.6.2. Policy Instruments	12
1.6.3. Who is responsible, who should be targeted?	14
1.7. Scope of this Book	15
References	16

Summary

In this chapter we explain why one needs to evaluate environmental costs and benefits. Cost-benefit analysis (CBA) is necessary for many choices of public policy, especially in the field of environmental protection, to avoid costly mistakes. Even when other, non-monetary criteria should also be taken into account, a CBA should be carried out whenever appropriate. Without monetary valuation of damage costs one can only do a cost-effectiveness analysis, as illustrated in Section 1.3. In Section 1.4 we explain how to determine the optimal level of pollution abatement, as simple example of a CBA. Impact pathway analysis (IPA), the methodology for quantifying damage costs or environmental benefits, is sketched in Section 1.5. The internalization of external costs is addressed in Section 1.6.

1.1. Why Quantify Environmental Benefits?

The answer emerges by asking another question: "how else can we decide how much to spend to protect the environment?" The simple demand for "zero pollution" sometimes made by well-meaning but naïve environmentalists is totally unrealistic: our economy would be paralyzed because the technologies for perfectly clean production do not exist ¹.

In the past most decisions about environmental policy were made without quantifying the benefits. During the nineteen sixties and seventies increasing pollution and growing prosperity led to increasing demands for cleaner air, and at the same time there was sufficient technological progress in the development of equipment such as flue gas desulfurization to allow cleanup without prohibitive costs. The demand for cleanup became overwhelming and environmental regulations were imposed without cost-benefit analysis.

Not only would the scientific basis for environmental cost-benefit analysis (CBA) have been inadequate in the past, but much simpler criteria seemed adequate for making decisions. Conditions in cities like London were initially so bad, and effects on health so serious that major actions were taken on the assumption that they were for the common good (an assumption borne out by subsequent analysis). The classic example is the Great London Smog of 1952 during which 4000 additional deaths were recorded above what would ordinarily have been expected. A second criterion was based on the idea that a toxic substance has no effect below a certain threshold dose. If that is the case, it is sufficient to reduce the emission of a pollutant below the level where even the highest doses remain below the threshold. Based on this idea standards for ambient air quality were developed, for example by the World Health Organization, and governments imposed regulations that force industry to reduce the emissions to reach these standards.

However, the situation is changing. Epidemiologists have not been able to find no-effect thresholds for air pollutants, in any case not at the level of an entire population. For example, the most recent guidelines of the World Health Organization say that there seems to be no such threshold for PM (particulate matter). The available evidence suggests that the exposure-response functions (ERF) are linear at low dose for PM, and probably for other air pollutants as well ². In particular for the neurotoxic impacts of Pb the ERF is at least linear without threshold and may be even be above the straight line at low dose. Linearity is already generally assumed for substances that initiate cancers.

At the same time the incremental cost of reducing the emission of pollutants (called "abatement cost" ³) increases sharply as lower emission levels are demanded. Thus the question "how much to spend?" acquires growing urgency, while the natural criterion for answering it by reference to a threshold has vanished. Even worse, we are facing a

¹ If you don't believe it, try to think of an economic activity that does not involve pollution. Maybe growing tomatoes in your yard and selling them at the local farmer's market? But few people live within walking distance of the local farmer's market, and even if you do, most of your customers have to drive or at least use a bicycle – and don't forget the pollution emitted during the production of a bicycle. Chemical and physical processes are by their very nature not "pure", i.e. they always produce at least some byproducts in addition to what we want. We can and should reduce pollution as much as is practical (in a sense to be defined below) but zero pollution is not feasible in an industrialized society.

² One implication of linear no-threshold ERFs is that the traditional preoccupation with pollution peaks is not really relevant: it is the long term average exposure that matters. Of course, since on average the peaks are proportional to the long term average exposure, reducing the peaks also reduces the average exposure.

³ Some authors, for instance IPCC, use "mitigation" instead of "abatement".

proliferation of small risks as ever more sensitive scientific methods identify ever more substances that can have harmful effects, possibly (or probably, in the case of many carcinogens) without safe threshold. Thus we have to deal with a new paradigm, and monetary valuation of environmental benefits is required to make our decisions consistent with our preferences. Optimal decisions are not obvious because of the complexity of the links.

Many people have objected to environmental CBA, feeling that one cannot assign monetary values to goods such as a beautiful landscape, an endangered species or human life. This objection is based on a fundamental misunderstanding of what is involved in the monetary valuation. In reality it is not the intrinsic value of the item in question but society's collective willingness to pay (WTP) to avoid losing the item. For instance our WTP (even our ability to pay) to avoid an anonymous premature death is limited, even if we feel that the value of life is infinite. In any case, we have to make decisions and a judgment about monetary values is implicit in our decisions. For example, if a city refuses to replace a level crossing by a bridge, at a cost x to avoid y traffic deaths, its "value of life" is less than x/y ; if the bridge is built, the implied value is at least x/y ⁴. Environmental CBA makes implicit judgments explicit. Stakeholders are free to disagree with the analysis, but need to justify why.

Ultimately the objective of a CBA of proposed policies or regulations is to render the decisions more consistent, in particular to avoid inconsistencies of the type where a billion is spent in one sector to avoid the loss of a life year while refusing to spend a thousand for the same thing in another sector – inconsistencies amply documented by Tengs and Graham [1996], Lutter, Morrall and Viscusi [1999], and Morrall [2003]. Tengs and Graham calculate that in the USA a more consistent allocation of resources could save about 0.5% of GDP without any reduction in the protection of the population. Inconsistent valuations are especially likely when regulations are imposed in response to the latest "risk of the day" that happened to attract intense attention in the media (dioxins, mad cow disease, asbestos, electromagnetic fields etc).⁵

Without monetary valuation of environmental goods one can do a cost-effectiveness analysis (CEA), i.e. rank choices with comparable outcomes, for instance options for reducing PM_{10} emission, or one can compare years of life saved by reducing air pollution versus years of life saved by reducing water pollution. But how can one compare choices with incommensurate outcomes, such as closing a factory to avoid pollution or keeping it going to avoid unemployment? Pay for the cost of putting particle filters on diesel buses to reduce particulate

⁴ The unfortunate term "value of statistical life" (VSL) used by economists often evokes hostility, "You cannot put a price on life" being a typical reaction. But that is a total misunderstanding of the problem. It is not "how much are you worth?" The objective is not to determine the intrinsic value of life, of a beautiful landscape, of a cultural monument, or a species threatened by extinction; rather it is the WTP to avoid the loss of the good in question. The WTP (including ability to pay) is limited, even for people who say that the good is priceless. Really VSL is the "willingness to pay for avoiding the risk of an anonymous premature death", and we prefer the term "value of prevented fatality" (VPF) which is more appropriate and less likely to evoke negative reactions. Another good term is "value of (mortality) risk reduction", which has been proposed in the USA.

⁵ Usually there is little correlation between the magnitude of a risk and the amount of media attention, or it may even be negative since small risks are more difficult to quantify: the greater the uncertainty, the more there is disagreement between the experts – and the greater is the entertainment value for the media. Much of the apparent irrationality of risk perception arises from binary thinking, a simple shortcut to help us deal with the complexities of most decisions: A is safe, B is not, ... Most of the time such shortcuts are better than getting paralyzed by an attempt to weigh quantitative criteria. But trouble comes when we are finding more and more small risks. Most potential new risks are nonzero and we, or the media, tend to assign them to the "not safe" category. So we have the cognitive illusion of living in an ever more dangerous world.

Ari Rabl 21/12/13 11:43

Deleted: should not

Ari Rabl 21/12/13 11:42

Deleted: the existence of a rare animal

emissions or continue to suffer the health impacts of the particles in our cities? Raise the cost of cars to make them cleaner? General principles such as sustainable development or the precautionary principle provide no guidance (except in their most extreme and totally impractical interpretation of demanding zero pollution) because the difficulties lie in the specifics of each situation.

The extra cost of a cleaner environment must be paid, ultimately by tax payer or consumer. For example, if a factory is forced to spend more for environmental protection (or pay a tax on pollution), this cost is passed on to the consumer – and if the cost is too high to be charged to the consumer because of competition from countries with less strict regulations, the owner of the factory has less incentive to continue the investments necessary to keep the factory up to date and will choose other more profitable investments instead; eventually the factory becomes unprofitable and is closed. Even if immediate tradeoffs do not cross budget categories, ultimately the money we spend on reducing pollution is not available for other good causes such as the education of our children.

Links can be subtle and unexpected. When evaluating a decision, one should not forget the consequences of the alternatives and the induced effects. For example, lowering the limit for the allowable emission of dioxins from waste incinerators will avoid some cancer deaths, but it will raise the cost of waste disposal. And poverty also kills, as demonstrated by numerous studies. The reasons are poor education, unhealthy housing, inability to pay for medical services, etc. For example, in the USA Keeney [1994] has found that for each \$ 5 to 10 million of cost imposed by a regulation there will be on average one additional premature death due to this cost. Lutter, Morrall, and Viscusi [1999] estimate that a \$15 million decrease in income is associated with the loss of an additional statistical life, and that therefore regulations that cost more than \$15 million per expected life saved are likely to cause a net increase in mortality.

The value of clean air is not infinite. With excessive pollution control the costs are not worth the benefits. There is a socially optimal level of pollution – which decreases with increasing prosperity and technological progress. The link to prosperity is complex. People with different levels of income and in different situations will rightly have different priorities for its allocation: access to food, clean water and shelter will, for example, come ahead of most people's priority for clean air. Problems arise when the actions of one group impact unequally on others. Of particular relevance here are the risks linked to climate change, where those living on a dollar a day will be at higher risk than those who are richer and contribute far more to greenhouse gas emissions. Likewise the costs and benefits of air pollution abatement are different for different income groups.

1.2. Costs Are Not the Only Criterion for Decisions

A cost-benefit analysis (CBA) should not be a simple automatic criterion for environmental decisions. The results have to be used with care because the uncertainties can be large, and it is too easy to manipulate the assumptions to get the result that a particular group might want to see.

Furthermore, other considerations may be as important as costs, especially equity (who pays and who benefits?). For many options to reduce air pollution the distribution of costs and benefits among the population is sufficiently uniform not to raise serious equity issues. But there are exceptions, for instance if low emission zones are created in cities by prohibiting the

Ari Rabl 21/12/13 11:56

Deleted: problematic

Ari Rabl 21/12/13 11:57

Deleted: This does not mean that a

use of older more polluting vehicles: the benefits accrue to all while the costs fall on the owners of the excluded vehicles. If suitable compensation schemes cannot be devised, a policy option may be problematic even if the total benefits are clearly larger than the total costs.

For the choice of energy systems one should take also into account issues such as supply security, the right to impose risks on future generations (nuclear wastes or global warming), the dangers of proliferation and the acceptability of a large accident. Such issues involve societal value judgments, beyond the costs one can quantify. That is not an argument against monetary valuation. Rather, the appropriate approach is to quantify the costs as much as possible as input into the decision process. For example, one may be able to evaluate equity implications explicitly in monetary terms, as is being done for the implications of a carbon tax by evaluating how the tax burden would be distributed among different socio-economic groups. Equity issues tend to weigh heavily in the decisions of elected officials because they want to be re-elected.

The question of acceptability complicates any quantification of mortality risks. Mortality risks can differ in the nature of the death (e.g. by accident, by cancer, or by other illness) as well as in attributes that influence the perception of a risk, for instance:

- is the risk voluntary or involuntary?
- is the risk natural or manmade?
- to what extent is it associated with an activity that is considered socially desirable?
- how much control does an individual have over the exposure or consequences?

Such attributes affect the importance that people place on avoiding a particular risk. This can confound even a direct comparison of risks in physical units (number of deaths or years of life lost), quite apart from any controversies surrounding the valuation in monetary terms.

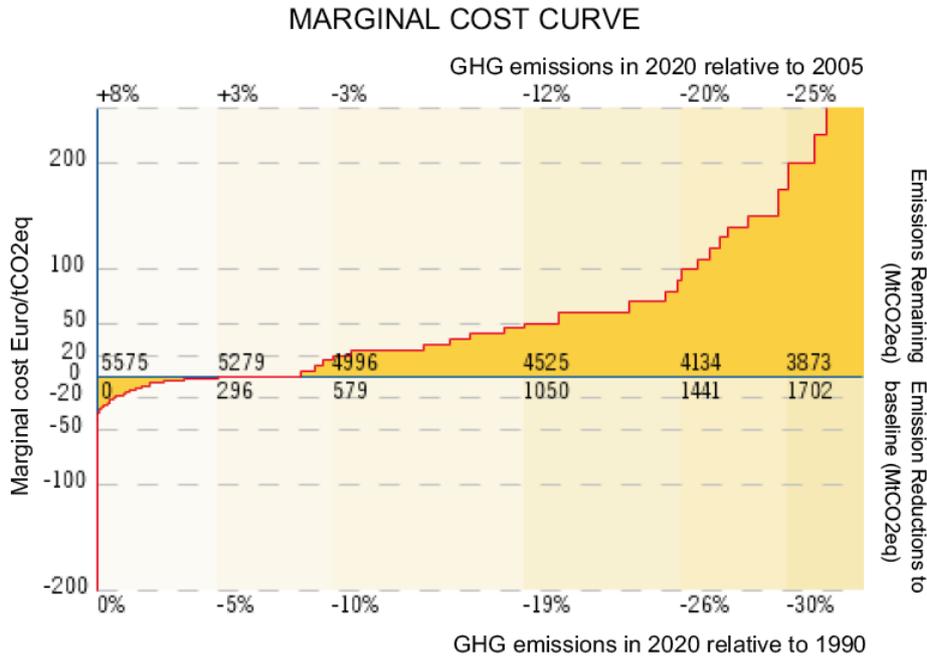
However, such limitations do not render a CBA useless. If the analysis has been carried out with care, clearly stating the underlying assumptions, it brings hidden consequences into the open and helps focus the debate on the facts. In particular it can indicate whether a proposed decision reflects true preferences or merely a cognitive illusion.

1.3. Cost-Effectiveness Analysis

To show what can and what cannot be done without evaluation of damage costs, let us look at cost-effectiveness analysis (CEA). CEA quantifies the costs and effectiveness of methods for achieving a goal, for instance reducing the emission of a pollutant, and then ranks them according to their ratio improvement/cost. As an example we show in Fig.1.1 the marginal abatement costs for greenhouse gas emissions for various technology options in the EU, as calculated by IIASA (the International Institute for Applied Systems Analysis) [2010]. For each option IIASA determined the cost and the potential reduction if the option is implemented in the entire EU. Of course, one should implement the less expensive ones before the more expensive ones. Therefore the options are presented in the order of increasing cost (from left to right), and the x-axis shows the cumulative emission reduction if the various technology choices are implemented in the order of increasing costs. In this particular example of a CEA the x-axis labels are a bit complicated because the emission reduction is shown in several different ways (as % reduction relative to 1990 and 2005, as cumulative reduction in Mt_{CO₂eq}/yr⁶, and as remaining emissions).⁷

⁶ The notation CO_{2eq} indicates that all greenhouse gases are included and expressed as equivalent CO₂ emissions.

Fig.1.1. Example of cost-effectiveness analysis: marginal abatement costs for various technology options in the EU. From IIASA [2010], reproduced with permission from the International Institute for Applied Systems Analysis (IIASA).



According to these data, up to 296 Mt_{CO_{2eq}}/yr can be avoided at negative abatement cost, because there are options that bring net savings. If the damage cost were equal to 50 €/t_{CO₂} (100 €/t_{CO₂}) the emissions can be reduced by as much as 1050 Mt_{CO_{2eq}}/yr (1441 Mt_{CO_{2eq}}/yr). That kind of information is valuable because it indicates how much can be achieved at what cost. But it does not indicate how much should be done. CEA is necessary but not sufficient. To determine the optimal level, one also needs to know the damage costs.

A further problem is that CEA typically focuses on the cost of achieving one particular goal without reference to other issues. For example, in the case given, no account is taken of other impacts of the measures introduced to reduce carbon emissions. Some of these will be beneficial, such as the reduction in regional air pollutant emissions (SO₂ etc.) associated with reduced fossil fuel use. Some of them will involve a trade-off of the carbon abatement benefit with other risks, for example those associated with nuclear power generation. CBA therefore provides a mechanism for a much more comprehensive assessment of the impacts of policies.

⁷ Note that the abatement costs are uncertain because for the most part they involve new technologies. Over time, as these technologies are applied more and more, their costs will decrease thanks to learning. For that reason abatement cost curves for the near term, such as Fig.1.1, show much higher costs than cost curves that are projected to the more distant future, with assumptions about learning rates, such as the marginal abatement cost curve in Fig.1.2b.

1.4. The Optimal Level of Pollution Abatement

Taken as a whole, society must pay the cost of pollution abatement and suffer the damage cost of the remaining pollution. To find the optimum one has to minimize the sum of abatement cost $C_{ab}(E)$ and damage cost $C_{dam}(E)$,

$$C_{tot}(E) = C_{dam}(E) + C_{ab}(E) \quad (1.1)$$

as function of the emission level E of the pollutant. Setting the derivative of C_{tot} equal to zero one finds that the optimal emission level E_{opt} of the pollutant corresponds to the point where

$$\frac{dC_{dam}}{dE} + \frac{dC_{ab}}{dE} = 0 \quad \text{at } E = E_{opt} \quad (1.2)$$

Economists call the derivative of the cost a marginal cost, and say that the optimum is where marginal damage cost = - marginal abatement cost.

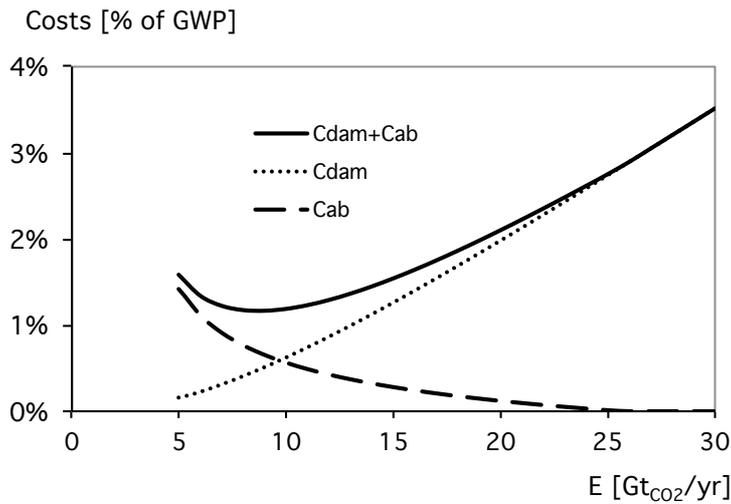
For the important case of pollutants with linear or near-linear dose-response functions (the case for the most important impacts of the classical air pollutants) the marginal damage cost is independent of E . For greenhouse gases the marginal damage cost increases with E . Fig.1.2 illustrates the optimization with an example, the abatement of worldwide CO_2 emissions. Of course, that is an extraordinarily complex problem (even if politics did not interfere with the search for the truth), and Fig.1.2. presents an extreme simplification, based on a simple steady state analysis [van der Zwaan and Rabl 2008]⁸. Part a) shows the damage cost C_{dam} and the abatement cost C_{ab} as well as their sum, Part b) their derivatives. The current emissions are 27 Gt_{CO_2}/yr . The optimal emission level is the one that minimizes the total cost. It is the point where the marginal damage and abatement costs are equal, 8.7 Gt_{CO_2}/yr (about a third of current emissions) under steady state conditions. Of course in reality the emissions and costs change over time and a more rigorous dynamic analysis is needed. Nonetheless, the key conclusion is quite robust, namely that the emissions should be reduced by a factor of about three relative to the business-as-usual scenario; that conclusion has been confirmed by a more rigorous dynamic analysis by Rabl and van der Zwaan [2009].

Strictly speaking there should be a third term in the optimization: the cost of defensive or adaptive measures. For example the damage of sea level rise due to CO_2 can be reduced by building dykes, and the damage of some materials due to SO_2 or O_3 can be reduced by appropriate surface treatments. If the damage, for a given emission level, can be reduced by defensive or adaptive measures, their cost C_{def} should be included in Eqs.1.1 and 1.2 by considering C_{dam} as net damage cost. For the classical air pollutants the potential of defensive measures is often so limited that it can be neglected in the optimization, but for greenhouse gases they are very important.

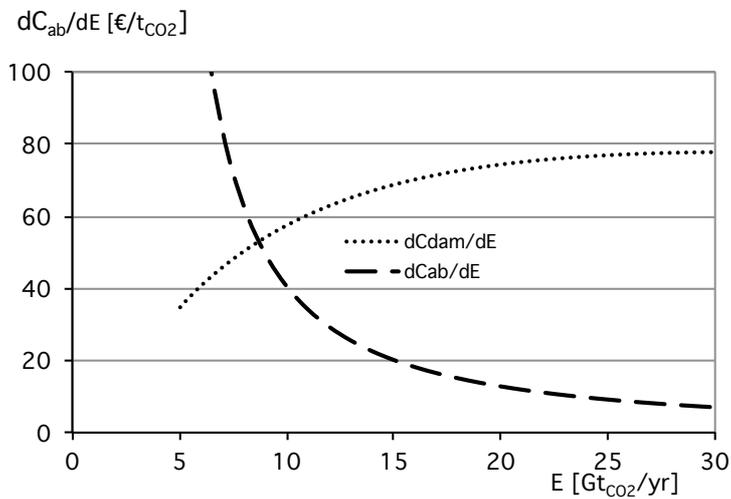
⁸ A more realistic dynamic analysis has been published by Rabl and van der Zwaan [2009], and some results can be found in Section 11.5.3.

Fig.1.2. Example of optimizing the emission level E : optimization of global CO_2 emissions, based on a simple steady state analysis.

a) total costs

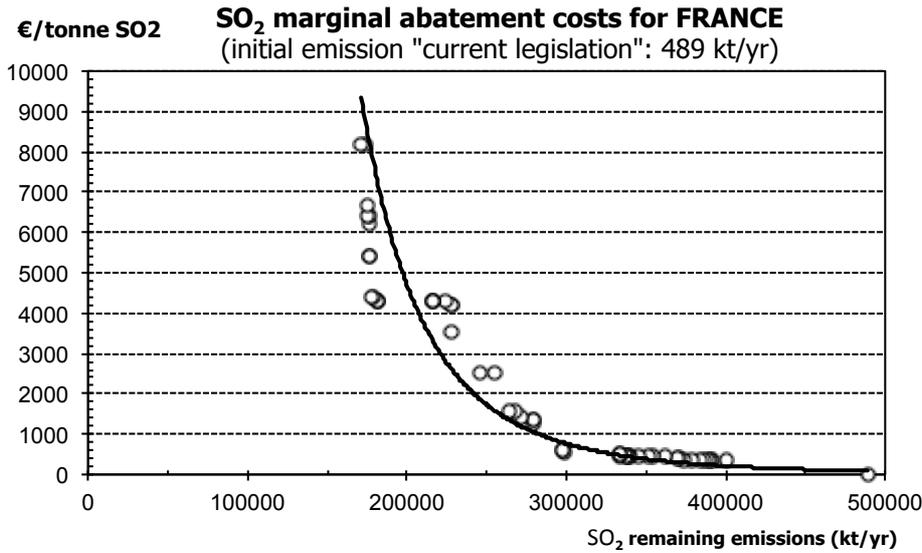


b) marginal costs



For another example consider the National Emission Ceilings Directive of the EU. This directive fixes limits for the annual emission of SO_2 , NO_x , VOC and NH_3 of each member country, to be attained by 2010. In preparation for the negotiations leading to these limits, IIASA was asked to assemble abatement cost data for each country. The data for France are shown in Fig.1.3; the points are from IIASA [1998], the line is our curve fit [Rabl, Spadaro and van der Zwaan 2005]. The rightmost point shows the emission level at the time, 489 kt/yr, corresponding to zero spending for additional abatement.

Fig.1.3. Marginal cost of SO₂ abatement as function of total emissions of France. The solid line shows our curve fit to the data points of IIASA [1998].



Example 1.1: The national emission ceiling for France was 375 kt_{SO₂}/yr in 2010, and the actual emissions were much lower, 303 kt_{SO₂}/yr in 2009. But how low should they be if the marginal damage cost for emissions in France is equal to the ExternE [2008] estimate 6800 €/t_{SO₂}?

Solution: Drawing a horizontal line at 6800 €/t_{SO₂} in Fig.1.3 we see that the social optimum is much lower, about 175 kt_{SO₂}/yr, less than half the current ceiling. Needless to say, the actual values of the directive are the result of political considerations where the social optimum has not been the primary criterion.

1.5. How to Quantify Environmental Benefits

1.5.1. Impact Pathway Analysis

Policy decisions must act on the sources of pollution. Therefore it is not sufficient to calculate the damage per exposure; one needs to know which source of a pollutant causes how much damage, i.e. what benefit one can expect from the reduction of specific emissions. This requires an impact pathway analysis (IPA), tracing the passage of the pollutant from where it is emitted to the affected receptors (population, crops, forests, buildings, etc.). The principal steps of this analysis can be grouped as follows:

- Emission: specification of the relevant technologies and pollutants (e. g. kg of NO_x emitted by power plant per GWh_e);
- Dispersion: calculation of increased pollutant concentrations in all affected regions (e. g. incremental concentration of ozone, using models of atmospheric dispersion and chemistry for ozone formation due to this NO_x);
- Impact: calculation of the dose from the increased concentration and calculation of impacts (damage in physical units) from this dose, using a exposure-response function (e. g. cases of asthma due to this increase in ozone);

Ari Rabl 21/12/13 14:46

Deleted: dose

- Cost: economic valuation of these impacts (e. g. multiplication by the cost of a case of asthma).

The impacts and costs are summed over all receptors of concern. The work involves a multidisciplinary system analysis, with inputs from engineers, dispersion modelers, epidemiologists, ecologists, and economists. By now the methodology is well developed, thanks to the ExternE project series which the European Commission, DG Research, has funded since 1991, and by analogous research in the USA [ORNL/RFF 1994, Abt 2004, NRC 2010].

Of course, the work is fraught with difficulties. Much of the required information is uncertain and in some cases even missing completely. However, the alternative of not doing any analysis is worse. Remember the basic rule of precaution: “think before you act!” Before taking a decision, evaluate its consequences as much as much as can reasonably be achieved. If a complete IPA is not feasible, for instance when no monetary values are available, carry the analysis as far as possible and then use other methods for choosing the most desirable action, such as risk-risk comparisons or cost-effectiveness analysis (i.e. a ranking of abatement costs to find which option has the lowest cost per avoided pollution).

Damage cost estimates are notorious for their large uncertainties (see Chapter 11), and many people have questioned the usefulness of all this work. The first reply to this critique is that even an uncertainty by a factor of three (the typical uncertainty of air pollution damage costs) is better than infinite uncertainty. Second, in many cases the benefits are either so much larger or so much smaller than the costs that the implication for a decision is clear even in the face of uncertainty. Third, if policy decisions are made without a significant bias in favor of either costs or benefits, some of the resulting decisions will err on the side of costs, others on the side of benefits. Rabl, Spadaro and van der Zwaan [2005] have examined the consequences of such unbiased errors for the abatement of NO_x, SO₂ and CO₂, and found a very reassuring result: compared to the minimal social cost that one would incur with perfect knowledge, the extra social cost due to errors is remarkably small, amounting to less than 10 to 20% in most cases even if the damage costs are in error by a factor three. But without any knowledge of the damage costs, the extra social cost could be very large.

Of course, the results of an IPA depend on the current state of scientific knowledge. Estimates of impacts and damage costs may grow or shrink. New impacts may turn out to be important. A bit of historical perspective may be good to keep us from being overconfident. For that reason we include, in Chapter 13 on electric power, a review of older fuel chain assessments.

1.5.2. Why Not Simply Ask People How Much They Value Each Impact?

Instead of all the complications of an IPA, why not simply ask people, by means of a questionnaire, how much they value each impact? It is really a matter of the appropriate expertise. The general public is of course the expert on general preferences and values. But not on dispersion modeling and exposure-response functions. It is appropriate to ask people who know what a cancer can be like, how much they are willing to pay to avoid a cancer. But asking them how much they care to reduce the emission of NO_x or dioxins is not, because they do not know how serious the impacts really are. After all, a rational policy must be based on real impacts, not on the fears of the moment.

Ari Rabl 21/12/13 14:48

Deleted: dose

1.6. External Costs and their Internalization

1.6.1. Definition of External Costs

In recent years the term external cost has been widely used to designate the damage costs of pollution. But we point out a risk of confusion because there are at least two definitions of external cost:

- 1) costs imposed on nonparticipants, that are not **taken into account** by the participants in a transaction;
- 2) costs imposed on nonparticipants, that are not **paid** by the participants in a transaction.

According to the first definition a damage cost is internalized if the polluter reduces the emissions to the socially optimal level, for example as a result of a regulation that imposes an emission limit. The second definition requires, in addition, that the polluter pay for the damage, for example with a pollution tax, to compensate the victims. In either case, the level of emissions is brought to the social optimum. But the corresponding damage cost is external only according to the second, not the first definition.

Many economics texts claim the first definition according to which only the damage beyond the social optimum is an external cost. However, that is not practical because to calculate an external cost according to that definition one would first have to determine the socially optimal emission level. Such a calculation is doubly difficult and the result doubly uncertain because most abatement costs are difficult to ascertain. Furthermore, the question of what % of the damage cost is already internalized is not relevant in practice because decisions should be based on CBA and minimization of total social cost (= private cost + damage cost). The % of damage cost that is already internalized is not needed for this minimization. In the wake of ExternE the term external cost is now generally used in the sense of damage cost (definition 2), and we will follow that practice.

As for internalization, there is a major difference between these two definitions of external cost. With a limitation of the emission (or with tradable permits that are given free) the polluter pays only the cost of abatement, i.e. the externality is internalized according to the first definition. But with a tax equal to the marginal damage (or equivalent tradable permits that are auctioned by the government) the polluter pays the cost of abatement as well as the damage cost of the remaining emissions; that's internalization according to the second definition.

As for compensation of the victims, perfect compensation is not feasible because identifying who suffers how much damage is too difficult and uncertain. However, a tax on air pollution can achieve compensation at least in an approximate average sense because we can all benefit from a reduction in air pollution.

There is a further complication with the definition of external costs. Some transactions impose costs on non-participants, but costs that are taken into account by the market. For example, an influx of new people to an area buying homes drives up house prices, making a purchase more difficult for the existing residents who have not yet bought a home. Another example is the shift to corn-based ethanol production, thus reducing the amount of corn for food and driving up the price of food for consumers who have nothing to do with the decision to produce ethanol. Such externalities are called pecuniary externalities, by contrast to the externalities due to pollution which operate outside the market. To emphasize the distinction, the latter are

sometimes called technological or real externalities. We will say a little more about pecuniary externalities in Section 6.3 of Chapter 6 on depletion of non-renewable resources.

To avoid ambiguities with the definition of external cost, we prefer to use the term damage cost for the externalities due to pollution. In any case one needs to know the damage costs, regardless of what fraction has been internalized according to which definition.

1.6.2. Policy Instruments

It is now generally recognized in democratic countries that the costs of pollution should be internalized. Internalization involves making the polluters reduce their emissions as if they were also the victim of their pollution (this simple definition of internalization applies equally to each of the two definitions of external cost shown above). The Coase theorem implies that internalization can be achieved without government intervention but only if the transaction costs are negligible, a condition that is certainly not satisfied for pollutants (for a good discussion of the Coase theorem in the environmental context, see Graves [2013]). Therefore government intervention is required.

Table 1.1 lists the principal types of regulations that the government can use for this purpose. Some of these policy instruments act directly on the emissions, others such as eco-labels and portfolio standards can effect emissions indirectly by discouraging the use of polluting processes or energy sources; for example a portfolio standard that requires a minimum % of “green electricity” raises the price of more polluting energy sources.

At one extreme are command-control regulations that impose rigid specific constraints, for instance a limit on the concentration of SO_2 in the flue gas of power plants. At the other extreme the government can impose certain general rules, for instance a tax per tonne of SO_2 , and let the market respond. The middle column of the table indicates whether the regulations are based on command-control (C) or on market mechanisms (M).

Command-control yields predictable results (e.g. the specified reduction of SO_2), but at greater cost than market mechanisms because all polluters must take the same action. Individual costs of pollution abatement are highly variable according to local circumstances, being for instance much higher for an industry that must install an expensive retrofit than for one that can include the pollution control equipment in the design of a new factory. Another drawback of command-control is the lack of incentives to do better than the regulation. Market based mechanism, in particular pollution taxes and tradable permits, avoid these drawbacks. For a more detailed comparison of command-control and market mechanisms, with examples, see Graves [2013].

A pollutant tax gives a clear signal to the polluter about the magnitude of the damage. Of course, in order to give a clear signal the tax has to be specific for each pollutant. The tax must not be a lumped tax, for example a tax per kWh on all the pollutants emitted by power plants, otherwise it would be like a supermarket without price tags where the consumer would only be given a final bill upon checkout. Of course, industrial polluters tend to pass the payment on to the consumers who will only see a general price increase, but the key point is that each tax has to be specific for each pollutant.

Under a pollution tax each polluter can choose how much of the pollutant to remove by abatement equipment and pay the tax on whatever remains. A pollution tax achieves

reductions at the lowest possible cost per avoided kg of pollutant (highest economic efficiency), and it provides an incentive to reduce emissions as much as is economically justified at the specified level of the tax; however, the magnitude of the realized reduction is difficult to predict.

*Table 1.1. Policy instruments for reducing pollution.
C = command and control, M = market based instruments.*

Type	C or M	Examples
Limits on emission of pollutants for specific technologies	C	Max. mg SO ₂ per m ³ of flue gas; max. g CO per km driven by cars
National emission ceilings	C or M ^a	Limit on tonnes of SO ₂ , NO _x , VOCs, CO ₂ , etc. emitted by a country
Choice of technologies	C	Usually by demanding "Best Available Technology" (BAT), e.g. flue gas desulfurization for coal or oil fired boilers
Major technology choices	C	Decisions in certain countries not to use nuclear power or to phase out existing nuclear plants
Subsidies for clean technologies	M	Tax credits for wind and solar Feed-in tariffs for electricity from wind and solar
Eco-labels	M	"printed on recycled paper"; "no chlorine used"; "energy star" label for computers
Pollution taxes	M	€/tonne of a pollutant
Tradable permits	M	government sets cap on number of permits (e.g. tonne of SO ₂), polluters can trade these permits
Portfolio standards	M	government sets minimum % for the market share of a clean technology (e.g. "zero emission" vehicles in California, or "green kWh" from solar energy) and industry adjusts the prices to achieve these goals.

^a depending on how a country chooses to implement the legislation

There is a policy instrument, tradable permits, that combines highest economic efficiency with predictable results – at least in theory. Under this system the government issues permits for a specified quantity of a pollutant that may be emitted in a region, and industry can freely buy or sell these permits. There are several variants, the two main distinctions being whether the government sells the permits at an auction or gives them away (for instance to each polluter according to last year's emission). Obviously, industry prefers the latter. In the USA tradable permits have been used for SO₂ already since the beginning of the 1990s, with great success: the cost per avoided kg turned out to be much lower than under the previous regime of command-control. Tradable permits, given free, are now also used in the EU for CO₂. If permits are given free, the allocation involves difficult and problematic negotiations with the concerned polluters.

The wild price swings of CO₂ permits in the EU since their introduction, in particular with prices dropping below 5 €/t_{CO2} in 2013, have brought to light a serious problem with permits in practice. Most industries have little short term flexibility for changing the emissions

because the emissions are determined by the technologies that are in place. If demand for a CO₂ intensive product goes up (down) temporarily, the most cost-effective response is to buy (sell) additional permits, rather than implementing process changes that tend to require time and investment. The recession since 2008 has curtailed demand for energy and thus for CO₂ permits. A relatively inelastic demand for permits without adjustment in the supply of permits (politically difficult to negotiate) implies large price swings. A CO₂ tax would have avoided such price swings which are problematic for the affected industries and for the trading system.

There has been some opposition to the idea of tradable permits, especially from people who misunderstand “permit” to mean unlimited license to pollute and do not recognize that the most widely used regulation, namely emission limits, is in effect a permit that is given away free but cannot be traded.

Some may wonder whether the moral limits to markets, so eloquently explained by Sandel [2012], are an argument against tradable permits or pollution taxes. As a striking example of carrying the idea of pollution taxes to an extreme, he considers a hypothetical fee for littering in the Grand Canyon. Such a fee would remove the moral stigma of littering, and people rich enough to pay and too lazy to carry their trash back out would be free to litter. When taxes or permits are used to limit the emission of pollutants, Sandel laments the loss of moral stigma. However, there are crucial differences between littering and the emission of pollutants. The ideal, zero litter, can easily be attained at negligible cost and the social control is sufficiently strong and direct to restrain potential violators. By contrast, the ideal of zero pollution would impose unacceptable costs on an industrial society and the social control is far too weak. Furthermore, pollution is driven by choices of the consumer who in most cases does not understand the relation between his/her choices and the associated pollution. Even the rare consumers who feel a sufficiently strong moral imperative to accept personal sacrifice have trouble knowing which goods are really cleaner. So there is no meaningful connection with moral stigma.

The great advantage of tradable permits or pollution taxes is to transmit the correct information about the damage cost of pollution in the price of all goods. That presupposes, of course, that the damage costs are known and that the government sets the right level for the permits or pollution taxes. For greenhouse gases the opposition to increased prices, coupled with disputes about international equity, may well prevent the imposition of the necessary regulations. To think about the consequences, we recommend reading “Collapse: How Societies Choose to Fail or Succeed” by Jared Diamond [2005].

This brief discussion cannot give more than a highly simplified overview, without regard to the many different ways any of these approaches can be implemented, or to the advantages and disadvantages they may offer in particular situations. Low administrative costs and ease of verification must be taken into account in choosing the most appropriate regulations. For example, unlike large power plants, monitoring of lawn mower emissions is not practical. And last but not least, a regulation is worthless if compliance is not verified and enforced.

1.6.3. Who is responsible, who should be targeted?

Whereas the “polluter pays” principle seems straightforward, in practice the question of who is the polluter and who should be targeted by an internalization instrument can be more complex. For example, in the case of pollutants that a consumer emits into the waste water (e.g. estrogen or testosterone from hormone replacement therapies, or pollutants from

cleaning products), the consumer can hardly do anything about it (other than using less polluting products), but the sewage company and/or the product manufacturer can. If they are forced to do it, they will pass the cost on to the consumer, so all can be automatically and correctly internalized.

Similar considerations apply to consumer products such as batteries. Here one of the policy options is to oblige the producer of batteries to use technologies without toxic components (Cd, Ni and Hg) even though that increases the cost; of course, the cost will be passed on to the consumer. Electronic equipment contains many potentially harmful materials that should be recycled or treated as toxic waste, and the most effective policy for keeping such materials out of municipal solid waste is to require manufacturers to take the equipment back when the consumer wants to discard it. The key consideration in such cases is “who can repair or minimize the problem for the lowest cost?”

Note that in any case it is crucial to aim the policy correctly at the right target, namely the specific pollutant that causes the problem. For example, an aggregated tax per kWh does not tell a power plant which pollutant contributes how much of the tax, so the power plant does not know how to allocate its abatement expenditures in an optimal manner from a social perspective. By contrast, a tax per kg of each pollutant, emitted by each source, does give a clear and correct signal.

The ultimate purpose of environmental CBA is to help formulate policies that provide the correct incentives for each actor in the economy to achieve the goal of optimal protection of our environment – in other words, make the incentives goal-compatible.

1.7. Scope of this Book

Most of this book deals with air pollution, although much of the methodology is also applicable to other forms of pollution. There are several reasons for this focus on air pollution, in addition to the fact that the authors are most familiar with its analysis. Air pollutants cause serious problems for the majority of the world’s population, especially in terms of global warming and health impacts. Even though the industrialized countries have succeeded in reducing the emission of several air pollutants, especially SO₂ and PM₁₀, the limitation of greenhouse gases has been far more difficult. In the developing world the reduction of air pollution is all the more challenging as these countries try to attain higher standards of living while their populations are increasing in most cases.

Soil pollution, at least in industrialized countries, is mostly a legacy of the past although continual vigilance is needed to prevent problems with new installations. Likewise the emission of most water pollutants has been greatly reduced in industrialized countries, with the glaring exception of nitrates and phosphates from agriculture.

The analysis of damage costs is simpler for air pollution than for water and soil pollution because air is a homogeneous medium where pollutants disperse over large areas, whereas water pollution is more localized and site-specific. Soil pollution is localized and very site-specific, requiring detailed local data for its analysis. Even though for the important sectors of energy production, waste management and transport the dominant impacts arise from air pollution, according to current assessments, we do not want to imply that water and soil pollution can be forgotten.

A word about the outline. It might seem most logical to organize this book according to the steps of the impact pathway analysis (IPA), followed by chapters with results and applications. However, we found such an approach awkward because of all the close links between the steps of an IPA. For example, the calculation of exposure by dispersion models is much simpler if the ERF is linear without threshold than if there is a threshold, and so we begin with a survey of the ERFs and the evidence for linearity. Also, we find it instructive to illustrate the “Uniform World Model”, an especially simple model, with examples for which we need specific ERFs for health impacts. Therefore we present health impacts before dispersion models. As an alternative one could organize the chapters according to impact categories but then much material would need to be repeated if one wants to avoid an excessive number of cross references. We finally chose an intermediate approach that allows us to write the chapters as relatively self-contained units without too much overlap or cross referencing.

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.
- Diamond JM. 2005. *Collapse: How Societies Choose to Fail or Succeed*. Viking Press.
- Graves P. 2013. *Environmental Economics: An Integrated Approach*. CRC Press/Taylor & Francis, Boca Raton, FL 33487.
- IIASA 1998. Janusz Cofala and Sanna Syri. “Sulfur emissions, abatement technologies and related costs for Europe in the RAINS model database”. International Institute of Applied Systems Analysis, IIASA Interim Report, IR-98-35, Appendix 6: Sulfur dioxide emission abatement cost curves for FRANCE (page 6.14)
- IIASA 2010. GAINS data sheet on greenhouse gas mitigation potentials. Version 2.1, April 2010. International Institute For Applied Systems Analysis, Laxenburg, Austria. <http://gains.iiasa.ac.at/index.php/home-page>
- Keeney RL 1994. "Mortality risks induced by the costs of regulations". *J. of Risk and Uncertainty*, vol.8, 95-110.
- Lutter R, Morrall M, Viscusi WK. 1999. “The Cost-Per-Life-Saved Cutoff for Safety-Enhancing Regulations”, *Economic Inquiry* 37, 599-608.
- Morrall JF. 2003. "Saving lives: A review of the record". *Journal of Risk and Uncertainty*, 2003; 27(3):221–237.
- 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.
- Rabl A and JV Spadaro. 1999. "Environmental Damages and Costs: an Analysis of Uncertainties". *Environment International*, vol.25 (1), 29-46.
- Rabl A and B. van der Zwaan. 2008. “Report on uncertainties and their effects”. Deliverable D.12.1 of CASES project. EC DG Research, project No 518294 SES6.

- Rabl A and B. van der Zwaan. 2009. "Cost-benefit analysis of climate change dynamics: uncertainties and the value of information". *Climatic Change*, Volume 96, Number 3 / October, 2009
- Rabl A, Spadaro JV, van der Zwaan B. 2005. "Uncertainty of Pollution Damage Cost Estimates: to What Extent does it Matter?". *Environmental Science & Technology*, vol.39(2), 399-408 (2005).
- Ramsberg JAL & L Sjöberg 1997. "The cost-effectiveness of life saving measures in Sweden". *Risk Analysis*, vol.17, 467-487.
- Sandel MJ. 2012. *What Money Can't Buy: The Moral Limits of Markets*. Farrar, Strauss & Giroux, New York.
- Spadaro JV & A Rabl. 2008. "Estimating the Uncertainty of Damage Costs of Pollution: a Simple Transparent Method and Typical Results". *Environmental Impact Assessment Review*, vol. 28 (2), 166-183.
- Tengs TO & JD Graham 1996. "The opportunity costs of haphazard social investment in life-saving", chapter 8, pp.167-184, of *Risks, Costs and Lives Saved*, R. W. Hahn, editor. Oxford University Press.
- Tengs TO, Adams ME, Pliskin JS, Safran DG, Siegel JE, Weinstein MC & Graham JD 1995. "Five hundred life-saving interventions and their cost-effectiveness". *Risk Analysis*, vol.15(3), pp.369-390.
- van der Zwaan, B.C.C., and A. Rabl. 2008. "Uncertainties of External Costs: How large are they and to what extent do they matter?", Section 1.16 in *The Social Cost of Electricity: Scenarios and Policy Implications*. Markandya A, Bigano A and Roberto Porchia R, editors. 2010. Fondazione Eni Enrico Mattei. Edward Elgar Publishing Ltd, Cheltenham, UK.