4.13 Description of the cost effectiveness methodology

4.13.1 The methodology

4.13.1.1 Introduction

In essence, the cost effectiveness methodology standardises the calculation of the cost and the effect of an environmental measure irrespective of the internal cost figures applied by the company itself. Its value lies in the ability to compare the calculated cost effectiveness with the indicative reference values and to evaluate the measures themselves.

The methodology used to calculate cost effectiveness is shown in figure 1. The following sections consider the various aspects of the figure. The methodology was developed primarily to calculate the cost effectiveness of end-of-pipe measures to reduce VOC, particulates, NO_x and SO_2 emissions into the atmosphere.

The calculation is made using a draft design of a selected measure. The draft design must generate all the information necessary to calculate cost effectiveness. In principle, draft designs incorporate measures that will comply with (non-binding) guidelines on the state of the art. The draft design should be provided by the company itself and assessed by the competent authority. Cost effectiveness may be calculated by either the company or the competent authority. The costs in a draft design may also be derived from the competent authority's own calculations.

For special situations that are not described in the method, reference is made to §4.13.3.

4.13.1.2 Interest rate and depreciation

The result of a cost calculation is highly dependent on the interest rate used. In the methodology, a fixed interest rate is applied of 10%. This 10% is a compromise between the nominal capital market interest rates and the internal rate of interest used by companies (the return on investment).

4.13.1.3 Depreciation method

In the methodology, investments are depreciated on an annuity basis. In principle, there are two methods of depreciation: straight-line and annuity. In practice investments are often depreciated on a straight-line basis. The annuity method, however, has the advantage that the annual charge is constant, making the methodology easier to use.

4.13.1.4 Depreciation period

The following depreciation periods are applied in the methodology:

- 10 years for the electro-mechanical part of the environmental investment;
- 25 years for the structural part of the environmental investment.

The electro-mechanical part of the investment comprises all equipment, complete with instrumentation and the like. The structural part includes halls, sheds, foundations, pipe bridges and the like. These structural investments are depreciated over a longer period because their lives are usually longer than ten years and they often remain in service after the original equipment is replaced. In practice, however, at least part of a structural investment is specific to the equipment and has to be removed when the equipment is written off, dismantled or taken out of service. If this is foreseen, such equipment-specific structures should be included in the electro-mechanical part of the investment and depreciated over ten years.

4.13.1.5 Annuity calculation

The annuity is a factor that expresses the annual cost of a non-recurring investment. The annuity is calculated from the interest rate plus depreciation as follows:

$$\text{Annuity} = \frac{i*(1 + i)^n}{(1 + i)^n - 1}$$

where i is the interest rate (dimensionless) and n is the depreciation period (in years). With an interest rate of 10% (i = 0.1), the annuity is 0.163 at a depreciation period of ten years and 0.110 at a depreciation period of 25 years.

The depreciation period commences the moment the equipment is taken into service. The cost of capital incurred before that moment is included in the non-recurring investments as 'interest costs during construction'.

Figure 1 Cost effectiveness methodology

a Costs

- Cost price
- Additional investments
- Non-recurring investments
- Extra depreciation of assets through disinvestment +

Total investments* annuity (= 0.163) = Capital cost

- Structural investments* $annuity_{struct.}$ (= 0.110) = Capital costs of structural investments

- Maintenance
- Service
- Other fixed operating costs +

Total fixed operating costs = Fixed operating costs

- Utilities (gas, electric power water, steam, etc.)
- Residue processing/emission levies
- Other variable operating costs +

Total variable operating costs = Variable operating costs +

= Total gross annual cost

- Revenues and savings = Revenues and savings –

= Total net annual cost

b Environmental effects

- Annual unabated emission = Annual unabated emission

- Annual remaining emission
- Annual emission during malfunctions
- Annual emission during maintenance +

Total annual remaining emission = Total annual remaining emission –

= Total annual emission reduction

c Cost effectiveness

- *Cost effectiveness* = $\frac{\textit{Total net annual cost}}{\textit{Total annual emission reduction}}$

Default values for calculation of cost effectiveness*

Sum of additional and non-recurring investments*: 30–250% of cost price (see table 1)

Non-recurring investments*: 25% of cost price

Fixed operating costs*: 3-5% of cost price and additional investments

Utility prices: From DACE price book (24)

Duration of malfunctions and maintenance: 2% of operating time

* Additional and non-recurring investment costs and fixed operating costs should preferably be derived from the draft design. The default values should be used only if the results of the draft design are not reliable.

4.13.2 Definition and explanation of terms

4.13.2.1 Cost price

The price that is paid to the supplier of the technique or to component suppliers. If a measure has not yet been implemented, the cost price together with the other investments and the operating costs is calculated in a cost engineering study. In such a study, the equipment used to achieve an emission reduction is scaled up to its true size before the costs are calculated.

4.13.2.2 Additional and non-recurring investments

Additional investments are the extra costs that are incurred to build the measure into the process. They include all manner of hardware: instrumentation, electrical connections and fittings, other utility fittings, pipelines, ducts and stacks, insulation and assembly. Structural investments made specifically for the measure are also included as additional investments. In part, the additional investments are specific to the situation and are determined by the ease with which the technique can be incorporated.

The additional investments should relate to the environmental measure only.

Non-recurring investments are the other costs that are necessary to bring the equipment into operation. They include engineering costs (including design and management during construction), fees and research costs for licensing procedures, interest costs during construction, notary fees, start-up costs and miscellaneous operating costs during the first year.

In practice, the additional investments are difficult to predict but may have a significant impact on cost effectiveness. The sum of the additional and non-recurring investments varies from 30% to 250% of cost price. This figure is determined chiefly by the degree to which the existing equipment and other facilities (for example buildings) need to be modified for the end-of-pipe technique and the complexity of the equipment (measurement and control equipment, etc.).
Table 1 provides a possible indication for use if the draft design is not sufficiently reliable.

Table 1 Additional and non-recurring investments in representative situations

New/existing installation*	Complex/simple installation**	Ratio of additional costs to basic costs*** (%)
New	Simple	+ 30 – 50
New	Complex	+ 50 – 100
Existing	Simple	+ 50 – 100
Existing	Complex	+ 100 – 250

* Assumption: A new building entails relatively low costs for process modification, structural facilities and piping and ducting (including fans and stacks).
** Assumption: A complex situation entails relatively high costs for study, preparation, engineering, construction and assembly supervision, start-up, instrumentation and electro-mechanical fittings.
*** The sum of the additional and non-recurring investments as a proportion of cost price.

4.13.2.3 Extra depreciation of assets through disinvestment

If the environmental measure makes certain process equipment or components redundant, must be depreciated as disinvestment. The extra depreciation is equal to the residual value of the material written off prematurely. This is applicable only in the case of non-environmental investments. Premature depreciation of environmental investments is considered in §4.13.3.2.

The extra depreciation is based on the total investment (the sum of cost price, additional investments and non-recurring investments) and the age of the assets prematurely written off. If the investment is older than ten years, the disinvestment is equal to nil. If the assets are younger than ten years, the extra depreciation through disinvestment is determined on the basis of table 2.

Table 2 The non-depreciated part of a non-environmental investment

Age (years)	Non-depreciated part (as a proportion of the total investment)
1	0.939
2	0.870
3	0.794
4	0.710
5	0.618
6	0.517
7	0.405
8	0.283
9	0.148
10	0

4.13.2.4 Structural investments

Structural investments include halls, sheds, outbuildings, foundations, pipe bridges and the like insofar as they are not specifically built for the environmental equipment. Equipment-specific structural investments are classified as additional investments.

4.13.2.5 Fixed operating costs

These are principally maintenance and service costs (including overhead) and insurance.

4.13.2.6 Variable operating costs

These are supply- and concentration-dependent costs such as auxiliary materials, utilities and residue processing. The variable costs are calculated for the maximum licensed operating time and capacity. Since the methodology is based on the cost of an environmental measure, standard utility charges are used wherever possible, as stated in the annual DACE publication (24).

4.13.2.7 Revenues and savings

This includes the expenditure that is avoided by implementing the measure, such as avoided environmental taxes, safety measures, maintenance, and consumption of raw materials and auxiliary materials. In addition, by-products may generate revenues, such as steam from heat recovery from after-burning or gypsum, sulphur or sulphuric acid from a desulphurisation plant.

4.13.2.8 Unabated emission

This is the emission in kg per annum that would be discharged if the abatement technique were not implemented. This emission is calculated for the maximum permitted operating time and capacity because the emission-reducing technique will be designed for this maximum.

If a measure has already been implemented, the unabated emission can be quantified, for example on the basis of:

- The emission before the measure is implemented if this is known from measurements and the production process has not changed significantly since the measurements were taken.

- The mass flow before the emission-reducing measure, if known.
- A mass balance. The use of solvents may be an indication of the VOC emission if no measure were taken. The sulphur content of the fuel may give an indication of the unabated SO_2 emission.
- The consumption of auxiliary chemicals. The quantity of calcium used, for example, may give an indication of the quantity of SO_2 removed.
- The quantity of separated residues, for example the volume of filtered particulates.

If a measure still has to be implemented, the unabated emission can be estimated on the basis of:
- Recent emission measurements.
- The current, licensed emission.
- Comparable process equipment in operation elsewhere (with or without the emission-reducing technique).
- Figures agreed with the company (if otherwise not available or for new installations).

4.13.2.9 Remaining emission

This is the emission in kg per annum following the implementation of a measure. It is determined from the licensed emission and the maximum licensed operating time and capacity or from measurement results (if lower than the licensed remaining emission). If production continues during maintenance or malfunctions of the environmental measure, the additional emissions during maintenance and malfunction are added to the emission discharged during normal operation. The duration of maintenance and malfunctions is taken to be set in the permit or based on the experience or estimates of the supplier. If such information is not available, 2% of the operating time may be used. This is relevant only if production can continue during maintenance and malfunction.

4.13.3 Calculations in exceptional cases

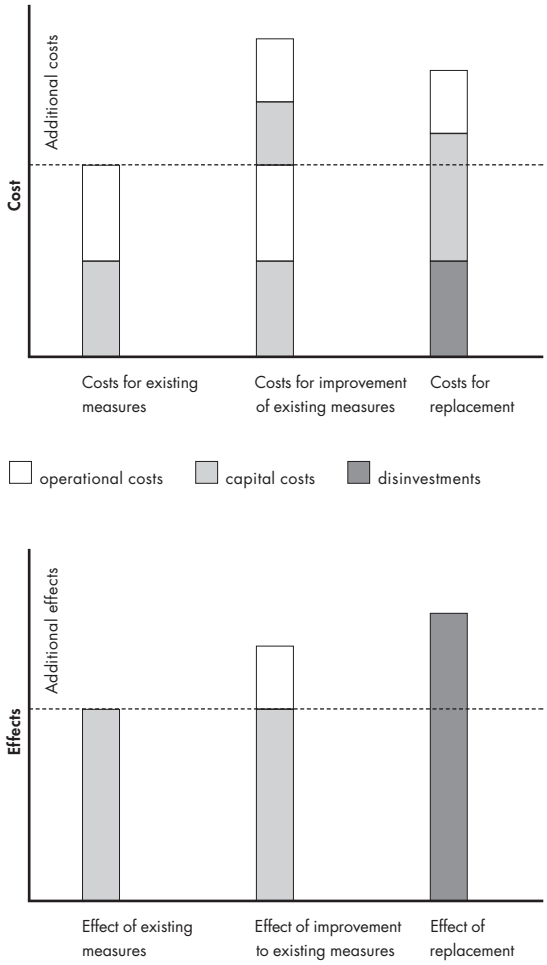
4.13.3.1 Safety measures

Safety measures are generally not regarded as 'environmental measures' in this methodology. If a safety measure has to be introduced for the implementation of an environmental measure, however, it is regarded as part of the environmental measure. If an environmental measure makes a safety measure redundant, a saving might be realised. If hardware that is not yet written off becomes redundant, there is an extra depreciation of assets through disinvestment. A reduction in the operating cost of safety measures also represents a saving.

4.13.3.2 Additional and replacement investments

The ALARA principle, which is embedded in Dutch environmental law, requires periodic checks to be made whether the standards set for the processes and the environmental measures are still in agreement with the latest knowledge and technical developments. If the competent authority believes an existing environmental measure is no longer adequate, the existing measure should be improved or replaced by a more reasonable measure. In such cases, both a marginal and a total cost effectiveness can be calculated. The marginal cost effectiveness is calculated using the additional cost and the additional effect. The total cost effectiveness is calculated using the total cost and the total effect. The terms additional costs and additional effects are illustrated in figure 2.

Figure 2 Total and marginal costs and effects of a measure



Existing measure

The cost of an existing measure is the sum of the operating cost and the cost of capital. If the existing measure is less than ten years old, the cost of capital is the product of the annuity and the original investment, adjusted for inflation by means of price indices in the DACE price book (24). If the existing measure is older than ten years, the cost of capital is equal to nil.

Improving an existing measure
An existing measure may be improved by either upgrading it (for example introducing an additional filter chamber) or by implementing an additional measure that raises the overall environmental performance of a particular component (for example a fabric filter behind a cyclone). On the improvement of an existing measure, the marginal cost is equal to the sum of the cost of capital and the operating costs incurred to improve the measure. The marginal effect is the effect attributable to the improvement. Marginal cost effectiveness is the quotient of these two. The total cost is the sum of the cost of the existing measure plus the cost of the additional measure. The total effect is the sum of the effects of the existing and of the additional measure. Total cost effectiveness is the quotient of the total effect and the total cost.

Replacement measure
The total cost of a replacement measure is the sum of the cost of capital, the operating cost for the replacement measure and the disinvestment. The calculation of extra depreciation through disinvestment is considered in §4.13.2.3. The total effect is the effect attributable to the replacement measure. Total cost effectiveness is the quotient of total cost and total effect.

Marginal cost effectiveness
Marginal cost is the difference between the total cost of the replacement measure and that of the existing measure. The marginal effect is the difference between the effect of the replacement measure and that of the existing measure. Marginal cost effectiveness is the quotient of marginal cost and marginal effect.

Marginal or total cost effectiveness?
Both marginal and total cost effectiveness have to be taken into account in practice. Since the elimination of a relatively small remaining emission is relatively expensive, marginal cost effectiveness is less favourable in many cases than total cost effectiveness. If a measure is assessed using the indicative reference values, its marginal cost effectiveness may not be acceptable even though its total cost effectiveness is acceptable. Since the indicative reference values (§2.11.3) are not suitable to assess marginal cost effectiveness, a separate method has been developed for improvement and replacement measures. The method is described below.

Method to assess the marginal cost effectiveness
There are two steps in a decision to improve or replace an existing measure:
1. Assess the acceptability of total cost effectiveness.
The total cost effectiveness of an improvement or replacement measure is assessed using the indicative reference value (§2.11.3). This assessment determines whether the total cost effectiveness is acceptable or not.
2. Assess marginal cost effectiveness.
If the total cost effectiveness is acceptable, the new measure's marginal cost effectiveness can then be assessed. The marginal cost effectiveness will in general be less favourable than the total cost effectiveness. If the marginal cost effectiveness is acceptable, the measure is considered to be acceptable.
The lower acceptable value for marginal cost effectiveness has been set at 1.5 times the indicative reference value (§2.11.3). The upper value is 4 times the indicative reference value. These values, though, should be used cautiously. If the cost effectiveness lies between the two values, a measure may be postponed for a number of years to compensate a company for equipment becoming redundant. The number of years' postponement will depend on the age of the existing measure, as shown in table 3. The number of years' postponement is calculated from the moment at which a new measure can be considered state of the art. This moment can be derived from documents that describe the best available technique (for example the NeR or the European BREFs).

Table 3 Determination of the number of years' postponement if marginal cost effectiveness is between 1.5 and 4 times the indicative reference value

Age of existing measure	Number of years' postponement*
2	9
4	7
6	6
8	5
10	3
15	1
20+	0

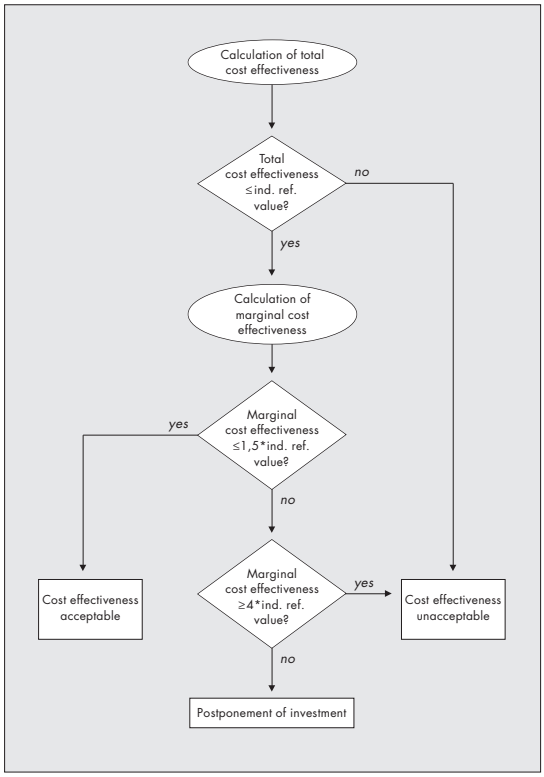
* The number of years' postponement is calculated from the moment a new measure is considered to be state of the art.

If the environmental measure is new, only the total cost effectiveness needs to be assessed against the indicative reference value. However, if several alternative environmental measures have only small differences in their environmental impact but significant cost differences, an additional evaluation of marginal cost effectiveness may be worthwhile, as it is with existing measures. The assessment of the marginal cost effectiveness is made using only the reference of four times the indicative reference value since a new measure cannot be postponed.

Figure 3 summarises the considerations schematically. Ultimately, one of three conclusions will be drawn:

- the improvement or replacement measure is acceptable and the measure is not postponed;
- the improvement or replacement measure is postponed to compensate the company for the extra depreciation of assets (applies only to existing equipment);
- the measure is not acceptable; the decision-making process is continued as shown in figure 1, §2.11.4 (N.B. This is not a postponement).

Figure 5 Decision-making process for additional and replacement investments



4.13.3.3 Cross-media effects

Most environmental measures have a greater impact on the environment than the effect for which they were designed and implemented. The basic rule in this methodology is that account is taken only of the effect for which the environmental measure is implemented. Other effects are not considered unless a measure is explicitly designed to reduce emissions of more than one component. In this case, an allocation method is used to calculate cost effectiveness.

Weightings are introduced to aggregate the different types of chemical substances. The weightings discount the fact that a reduction in the emission of component A by one kilogram is worth more than a reduction in the emission of the less harmful component B by one kilogram or less.

The proportion of the total cost that must be allocated to reducing one of several components can be calculated using the following formula:

$$TC_A = \frac{Q_A{}^*wf_A}{Q_A{}^*wf_A + Q_B{}^*wf_B} \quad {}^* TC$$

where TC_A is the total cost that can be allocated to the reduction of component A (in Euros); TC is the total cost of the measure (in Euros); Q_A and Q_B are the quantitative reduction in A and B emissions respectively (both in kg); and wf_A and wf_B are the weightings for A and B respectively (dimensionless).

The cost effectiveness of reducing component A emissions (in euros per kg) can then be calculated as:

$$CE_A = \frac{TC_A}{Q_A}$$

The weightings are based on the emission limit values stated in the NeR. The adoption of these limit values took account of the components' toxicological and other environmental impacts. The advantage of this is that it allows relevant emissions to be weighted. In practice, if component A's emission limit value is four times lower than component B's, the reduction of emissions of substance A is weighted four times as heavily. The dimensionless weighting, wf, is defined as one hundred divided by the emission limit value as formulated in the NeR. Table 4 shows a number of weightings.

Table 4 Weightings

NeR class	Emission limit value ($mg/m^3{}_0$)	Weighting (dimensionless)
C.1	0.1	1000
C.2	1	100
C.3	5	20
particulate	10/25/50*	10/4/2*
sA.1	0.2	500
sA.2	1	100
sA.3	5	20
gA.1	1	100
gA.2	5	20
gA.3	30	3.3
gA.4	200	0.5
gO.1	20	5
gO.2	100	1
gO.3	150	0.6
sO.1	10/25/50*	10/4/2*
sO.2	10/25/50*	10/4/2*
sO.3	10/25/50*	10/4/2*
SO_x (as SO_2)	200	0.5
NO_x (as NO_2)	200	0.5

* depending on the mass flow and the technical feasibility of applying filters

The physical or economic background to this weighting method is limited. The weightings are therefore used only to determine what proportion of the cost can be attributed to reducing emissions of component A and B.

4.13.3.4 Simultaneous environmental and non-environmental impact

In some cases a measure may have both an environmental impact and a non-environmental impact. The second impact may relate to, for example, working conditions or safety. In such cases, the measure cannot be treated solely as an environmental measure; part of it must be treated as working conditions or safety measure.
To separate the environmental investment from the non-environmental investment, a theoretical minimum working conditions or safety measure must be defined in order to determine its cost. This minimum other cost is deducted from the total cost to produce the environmental cost.

4.13.3.5 Capacity changes after implementation of an environmental measure

An increase or decrease in a process's actual production volume in the period in which a measure is in operation will not influence the cost effectiveness calculated using this methodology since both the emission and the measure are extrapolated for the maximum licensed capacity.

If the licensed capacity changes in the period in which a measure is in operation, cost effectiveness will be influenced. Both the unabated emission and the emission after implementation of the measure are calculated for the capacity permitted under the new licence. If capacity increases on account of a new production line coming on stream, environmental measures can be introduced for that line. In such cases, the measures' cost effectiveness is calculated on the cost and effect of that production line.

4.13.3.6 Process-integrated measures

Calculating the cost effectiveness of a process-integrated measure is more problematic since it is difficult to discern the specific environmental costs and benefits of process integrated measures. More exceptions will also have to be allowed for. In many cases, a measure will be introduced for non-environmental reasons or capacity changes may be introduced simultaneously. In principle, the methodology described above is also appropriate for process-integrated measures. It should be noted, though, that neither the methodology nor the indicative reference values have been adequately tested for such measures.