International Journal of Earth, Energy and Environmental Sciences
ISSN: 2517-942X
Vol:2, No:5, 2008

Assessment of Pollution Reduction

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Abstract—Environmental investments, including ecological projects, relating to the protection of atmosphere are today a need. However, investing in the environment should be based on rational management rules. This comes across a problem of selecting a method to assess substances reduced during projects. Therefore, a method allowing for the assessment of decision rationality has to be found.

The purpose of this article is to present and systematise pollution reduction assessment methods and illustrate theoretical analyses with empirical data.

Empirical results confirm theoretical considerations, which proved that the only method for judging pollution reduction, free of apparent disadvantages, is the Eco 99-ratio method. To make decisions on environmental projects, financing institutions should take into account a rationality rule. Therefore the Eco 99-ratio method could be applied to make decisions relating to environmental investments in the area of air protection.

Keywords—Assessment of pollution reduction, costs of environmental protection, efficiency of environmental investments.

I. Introduction

ENVIRONMENT protection investments, including ecological projects, relating to the protection of atmosphere are today a need. There are many reasons for investing in the environment, starting from economic loss generated by pollution[1], through the size of air pollutant emission[2] to environmental and social damages[3]. However, investing in the environment should be based on rational management rules. In this case, rationality is understood as the selection of the minimum value of the quotient of investment expenditure and specific pollutant toxicity. Toxicity is represented as the product of reduced pollutant weight and a specific toxicity ratio.

Thus, we have to find a method to assess whether decisions made are rational. Here, we come across a problem of the evaluation of investment effectiveness in terms of the selection of a method to assess substances or compounds reduced as a result of the project. Various pollutants cause different losses and the comparison of tangible effects is hardly useful from an economic point of view. Therefore, in such studies, the said tangible effects have to be made comparable.

The purpose of the article is to present and systematise methods of pollution reduction assessment and illustrate theoretical considerations with empirical data. By comparing various methods, we will pay attention to those that assess effects obtained in a complex manner, in empirical tests.

Data used in the article come from the Provincial Fund for Environmental Protection and Water Management in Gdańsk (WFOŚiGW) and cover the period of 1996-2006. The study refers to investments, mainly heating system modernisations, carried out to protect the atmosphere. Reduction refers to the following substances: carbon dioxide – CO_2, carbon monoxide – CO, sulphur monoxides expressed in the equivalent of sulphur dioxide – SO_2, nitrogen monoxides, expressed in the equivalent of nitrogen dioxide – NO_2, and dusts.

II. Pollution Reduction Assessment Methods

To calculate investment expenditure per reduction of particular pollutants, these substances have to be made comparable based on toxicity ratios for each of them. Later, this will allow calculating the cost of reducing 1 kg of a given pollutant. Table I presents toxicity ratios used to assess pollution reduction.

TABLE I
AIR POLLUTION TOXICITY RATIOS (TI)

Substances	MASS METHOD	WFOŚIGW METHOD	NDS[1] METHOD	Fee method	Eco-99 method
dusts	k = 1	k = 2.9	k = 1	k = 0.76	k = 2.86
SO_2	k = 1	k = 1	k = 1	k = 1	k =1.5
NO_2	k = 1	k = 2.9	k = 1	k = 1	k = 2.74
CO	k = 1	k = 0.5	k = 0.004	k = 0.26	k = 0.0189
CO_2	k = 1	k = 0	k = 0.00224	k = 0.53	k = 0.00545

Source: own findings

In the mass method, all ratios are equal to one since this method does not define toxicity differences between pollutants. In the equivalent emission method by WFOŚiGW, ratios come from guidelines of the Ministry for the Protection of Environment, Natural Resources and Forestry[4]. They were calculated on the basis of load bearing capacity ratios for pollutants from power fuel combustion. In the NDS NDS[5]

[1] Compare: Leipert Ch. (1989) *Die heimlichen Kosten des Fortschritts. Wie Umweltzerstörung das Wirtschaftswachstum fördert*; Fischer Verlag, Frankfurt am Main, p. 36-42, Famielec J. (1999) *Straty i korzyści ekologiczne w gospodarce narodowej*, PWN, Warsaw – Kraków, p. 212-242.

[2] Statistical Annual on Environmental Protection (2002), GUS, Warsaw, p. 220-231.

[3] Jankowska-Kłapkowska A. (1991) "System ekologiczno-ekonomicznych ocen procesu wzrostu i rozwoju społeczno-gospodarczego" [in:] *Ekologiczne bariery wzrostu i rozwoju społeczno-gospodarczego w Polsce,* Kraków, p. 134-137.

[4] Information materials and instructions of MOŚZNiL, publication 1/96, 1996, Warsaw.

[5] Compare: Method by Schaltegger & Sturm; Kowalski Z., (2000) „Ocena ekologiczna wariantów metody chemicznej oczyszczania pogarbarskich

method, ratios were calculated in accordance with top admissible concentration of air pollutants based on the Attachment to the Order by the Minister of Environmental Protection[6]. In the fee method, ratios are constructed on the basis of applicable fees for environment utilisation[7]. In the Eco-99 method, ratios were calculated based on scores used by LCA[8]. This method assigns various number of points to specific substances depending on their negative impact on the environment and human health.

The most important issue in the selection of a method to be used to calculate costs of specific pollutant reduction is to find a method that will reliably reflect the actual share of such a substance in total compounds reduced.

A. Mass Method

The simplest and least precise method is a mass method allocating equal shares to each compound.

In this case, equivalent emission is simply the sum of investment effects. It is calculated in accordance with the following formula:

$$Er = Ef\,dusts + Ef\,SO_2 + Ef\,NO_2 + Ef\,CO + Ef\,CO_2 \qquad (1)$$

$$Er = \sum_{i=1}^{5} Ef_i$$

where:
Er – equivalent emission in kg
Ef_i – effect of one compound reduction in kg
i = 1.2...5, assigned consecutively 1= dusts, 2 = SO_2, 3 = NO_2, 4 = CO, 5 = CO_2

An average cost of the reduction of 1 kg of one pollutant is calculated as follows:

$$K_{R\text{-}kg} = \frac{Kz}{Er} \qquad (2)$$

where:
$K_{R\text{-}kg}$ – cost of the reduction of 1 kg of any compound, in PLN/kg
Kz – total investment cost in PLN

B. Equivalent Emission Method by WFOŚiGW

A method applied by specific funds, including the Provincial Fund for Environmental Protection and Water Management in Gdańsk, is an equivalent emission method. This method does not take into account the reduction of carbon dioxide.

Equivalent emission used to calculate pollution reduction costs, including specific toxicity ratios[9], is calculated in accordance with the following formula:

$$Er = T_1 * Ef\,dusts + T_2 * Ef\,SO_2 + T_3 * Ef\,NO_2 + T_4 * Ef\,CO \qquad (3)$$

i.e.:

$$Er = \sum_{i=1}^{4} T_i * Ef_i$$

where:
T_i – toxicity ratio (Table I)
Other symbols like in (1)

The cost of 1 kg of pollutant ‘i’ is calculated on the basis of the following formula:

$$K_{R\text{-}Mg} = \frac{Kz * T_i}{Er} \qquad (4)$$

C. Equivalent Emission Method by NDS

The equivalent emission method based on Top Admissible Concentration of analysed pollutants is a method similar to the previous one, however the equivalent emission formula takes account of the share of carbon dioxide[10].

Equivalent emission assigns the same toxicity to sulphur dioxide, dusts and nitrogen monoxides expressed in the equivalent of nitrogen dioxide, and much a smaller toxicity to carbon monoxide and dioxide. It is calculated in accordance with a formula similar to the formula (3), where i = 1,2..5, while 5 = carbon dioxide[11].

The cost of 1 kg of pollution is calculated on the basis of the formula (4) and toxicity ratios are determined in accordance with NDS (Table I).

D. Fee Method

The fee method is well described in the literature[12]. To compare substances, the amount of fees for pollutant emission determined by the State is taken into account.

Equivalent emission is calculated on the basis of the formula (3) and toxicity ratios are determined on the basis of fees for environment utilisation (Table I).

Thus, the cost of the reduction of 1 kg of pollutants is calculated in accordance with the formula (4).

E. Eco99 Ratio Method

The Eco-99 ratio method is used to define LCA by assigning various Eco-points, which are the sum of

ścieków chromowych” [in:] *Ekologia wyrobów*, Materials from the First Conference, AE w Krakowie, Kraków.

6 Journal of Laws 1998.55.355, Admissible concentration of air pollutants.

7 M.P.2002.49.715, Fees for environment utilisation for 2002. Attachment 2 – Unit fees for gases or dusts emitted to the air.

8 Life Cycle Assessment, Compare: Buse M., Thuer M., (1996) „Life Cycle Assessment for Ecological Processes” [in:] *Proceeding of the 12th International Congress of Chemical and Process Engineering CHISA, Prague, p. 25-30;* Nierzwicki W., M. Richert (2002) *Ekologiczne uwarunkowania działalności gospodarczej,* Wydawnictwo WSZ, Gdańsk, p. 11-33.

9 Compare: Table I.

10 Amounts of top admissible concentrations for all analysed substances, except for carbon dioxide, were determined in the natural environment. For carbon dioxide there are no top admissible concentrations in the natural environment, thus, in this case, NDS refers to human working environment.

11 Compare: Table 1.

12 Gollinger-Tarajko M. (2002), „Metody oceny ekologicznej i ekonomicznej modernizacji procesów technologicznych”, Zeszyty Naukowe, Seria Specjalna: Monografie nr 153, Akademia Ekonomiczna w Krakowie, Kraków, p. 175-177., Borys T. (1998) „Teoretyczne aspekty konstruowania wskaźników ekorozwoju” [in:] *Sterowanie ekorozwojem,* Wydawnictwo Politechniki Białostockiej, Białystok.

representative environmental load and human life ratios, to specific substances[13].

Equivalent emission whose toxicity ratios are determined by the negative impact of a given substance is calculated in accordance with the formula (3).

The cost of the reduction of 1 kg of pollutants is calculated in accordance with the formula (4).

II. Evaluation of Investment Rationality in 1996-2006

TABLE II
INVESTMENT EXPENDITURE PRICE INDEXES IN 1996 – 2006

Current year	(A) Previous year = 100	(B) 1996=100
1996	100	100
1997	113.7	113.70
1998	109.3	124.27
1999	105.9	131.61
2000	105.3	138.58
2001	101.2	140.24
2002	100.3	140.67
2003	100.1	142.22
2004	102.5	145.77
2005	100.9	147.08
2006	101.2	148.84

Source: own analysis based on the Statistical Annual, GUS, 2003-2005, Warsaw, p. 437 and p. 516 and the Statistical Bulletin No. 2/2006 and 7/2007 GUS, Warsaw, Table 36, p. 121.

Based on data received from the Provincial Fund for Environmental Protection and Water Management in Gdańsk, 294 projects carried out in 1996-2006 were studied. During the respective analysed years, 31, 18, 32, 35, 24, 35, 36, 30, 29, 20 and 18 projects were carried out. All of them generated positive environmental effects by reducing the weight of pollutants.

Investment expenditure was converted into fixed prices of 1996 based on investment expenditure price indexes[14].

Investment expenditure converted into fixed prices of 1996 are presented for each of the methods separately (Tables III-VII).

Methods applied to make pollutants reduced as a result of environmental projects comparable were analysed in order to select a method which could be useful to make a decision on a given investment upon certain conditions.

A. Application of the Mass Method

The first of the above methods is the mass method, which does not use toxicity ratios for analysed compounds. Table III shows that average costs of investment expenditures per 1 kg of the reduction of analysed compounds differ in particular years, but without any visible trend. An untypical observation may be an average cost of the reduction of 1 kg of pollutants in 1996, which amounts to PLN 0.9 per kg since in the following years average costs are much higher. Analysing average costs of the reduction of 1 kg of pollutants in 1997 – 2006, we observe a decreasing trend: average costs drop. From an economic point of view, rational investments are those where the relation of investment expenditure to the reduced mass of a given pollutant is the smallest one.

TABLE III
COSTS OF THE REDUCTION OF 1 KG OF POLLUTANTS IN ACCORDANCE WITH THE MASS METHOD [PLN/KG]

Year	1996	1998	2000	2002	2003	2004	2006
Minimum costs	0.00	2.17	0.12	0.11	0.11	0.01	0.63
Average costs	0.92	18.3	4.35	2.15	2.91	2.06	1.75
Maximum costs	7.86	49.2	27.9	12.9	10.2	11.60	5.18

Source: own findings

According to the rationality rule, investments representing a small relation of expenditure to the mass of reduced pollutants should be carried out as first, and then investments of bigger expenses should be taken. Unfortunately, this is not the case in this method since average costs of the reduction of 1 kg of compounds calculated during the years do not decrease.

The mass method, which does not define various toxicity ratios for analysed substances, weights them equally, i.e. treats them identically in terms of toxicity. Therefore, Table III presents only one series of numbers since they are identical for all analysed compounds. This is the same as if we mixed apples with pears, saying that this is the same fruit. An identical relation appears in the case of chemical substances since, leaving aside the fact that, from a chemical point of view, these are completely different compounds having completely different physical and chemical properties, from an environmental point of view, they cause different problems and threats to the environment. From an economic point of view, taking into account economic loss and damage caused by specific pollutants, such an identical treatment of substances is not reasonable, either.

B. Application of Equivalent Emission Method by Wfośigw, Equivalent Emission Method by NDS and Fee Method

These three methods have some gaps and disadvantages, i.e. they do not include certain substances, or some additional assumptions have to be made[15] to construct a correct equivalent emission formula.

[13] Compare: Vigon B.W., Jensen A., (1995) *Life Cycle Assessment Data Quality and Databasis Protitione Survey, „Journal of Cleaner Production", 1995, No. 3.*

[14] Statistical Annual (2003-2005), Investment expenditure growth (fixed prices), GUS, p. 516.

[15] Compare: footnote 11.

The first equivalent emission method in this group is the method consistent with WFOŚiGW, whose biggest disadvantage is the fact that its formula does not take into account carbon dioxide. In the mass of substances reduced during air protection investments, a certain amount of this compound are eliminated every time, thus its share should be included in the total mass of reduced substances. And it is not an auxiliary substance eliminated only occasionally together with the reduction of other less harmful pollutants. Let's remember that Poland undertook to reduce the emission of carbon dioxide given more and more severe climate changes caused by a greenhouse effect.

TABLE IV
COSTS OF THE REDUCTION OF 1 KG OF POLLUTANTS IN ACCORDANCE WITH THE WFOŚIGW METHOD [PLN/KG]

	1996	1998	2000	2002	2003	2004	2006
SO_2	0.1	1.8	2.76	2.5	2.6	2.1	12.5
	13.5	17.5	109	42.5	43.3	23.1	44.9
	82.7	40.9	1047	406.7	291.8	115	184.3
NO_2	0.3	5.2	8.0	2.5	7.6	6.2	36.4
	46.9	66.5	306	41.6	260.0	66.8	122.9
	239.9	571.	3037	406.7	4019	335	534.5
dust	0.3	5.2	8.0	2.5	7.6	6.2	36.4
	46.9	66.5	306	41.6	260.0	66.8	122.9
	239.9	571.	3037	406.7	4019	335	534.5
CO	0.1	0.9	1.4	2.5	1.3	1.1	6.3
	8.1	11.5	52.8	1009	44.8	11.5	75.9
	41.4	98.5	524	33875	693.0	57.8	984.6

Source: own findings

Analysis average costs of particular air pollutant reduction obtained through this method, we may observe that, during the analysed years, the most funds were spent for the reduction of nitrogen oxides and the least funds were spent for the reduction of carbon monoxide. There were also significant differences between minimum and maximum values for all compounds. It seems that some of those values are much too big since comparing calculated costs to fees borne on environment utilisation; we may draw a conclusion that the investments were not rational.

TABLE V
COSTS OF THE REDUCTION OF 1 KG OF POLLUTANTS IN ACCORDANCE WITH THE NDS METHOD [PLN/KG]

	1996	1998	2000	2002	2003	2004	2006
SO_2	0.52	5.20	7.20	6.46	0.58	1.37	34.51
	39.60	51.93	215.0	95.06	196.5	54.30	102.62
	202.26	119.9	2532	645.9	2970	312.8	292.62
NO_2	0.52	5.20	7.20	6.46	0.58	1.37	34.51
	39.60	51.93	244.3	95.06	196.5	54.30	102.62
	202.26	119.9	2532	645.9	2970	312.8	292.62
dust	0.52	5.20	7.20	6.46	0.58	1.37	34.51
	39.60	51.93	215.1	93.44	196.5	54.30	102.62
	202.26	119.9	2532	645.9	2970	312.8	292.62
CO	0.06	0.02	0.03	0.03	0.000	0.005	0.14
	8.08	0.27	0.98	2.79	291.1	0.22	0.68
	41.37	2.33	10.13	84.89	5025	1.25	5.28

Source: own findings

Another method is the one based on NDS, which includes carbon dioxide, but a toxicity ratio for this compound is calculated differently to other compounds, i.e. in a different environment. This is an assumption which may significantly distort the results of actual costs of the reduction of 1 kg of carbon dioxide. While conversion of all substances to working environment would be even a bigger error since investments usually consist in the reduction of pollutants in the air.

The table shows that reduction costs are identical in the case of carbon dioxide, nitrogen oxides and dusts. This is not, however reliable from the point of chemistry, environmental protection or economy for reasons mentioned above. While, smaller costs of carbon monoxide and dioxide seem reliable. We may not observe here, like previously, a trend of increasing reduction costs in the analysed years.

The last method, having certain gaps, is the fee method based on fees on environment utilisations applied in Poland. This is a method commonly used in the world to make compounds comparable and, in the literature; it is defined as one of more correct since it reliably defines costs of the reduction of 1 kg of pollutants as compared to current corporate expenses. However, in the case of investments co-financed by specific funds, there is a certain error in the definition of a dust toxicity ratio since dusts are not broken down into defined chemical compounds, but they are treated as a whole, simply as dusts. This assumption may also influence the results causing certain deviations. The assumption concerning projects carried out to protect atmosphere allocates all dusts, reduced as a result of the investment, to the category of dusts coming from fuel combustion since most analysed investments consist in the modernisation of heating systems.

TABLE VI
COSTS OF THE REDUCTION OF 1 KG OF POLLUTANTS IN ACCORDANCE WITH THE FEE METHOD [PLN/KG]

	1996	1998	2000	2002	2003	2004	2006
SO_2	0.002	4.30	0.23	0.21	0.11	0.01	1.19
	1.70	38.12	8.72	4.08	2.77	2.09	3.30
	13.81	97.93	62.60	22.55	12.50	12.19	9.81
NO_2	0.00	4.30	0.23	0.21	0.11	0.01	1.19
	1.70	38.12	8.80	4.08	2.77	2.09	3.30
	13.81	97.93	62.60	22.55	12.50	12.19	9.81
dust	0.00	3.27	0.18	0.16	0.08	0.004	0.9
	1.29	28.97	6.63	4.11	1.93	1.59	2.34
	10.50	74.43	47.57	38.48	9.50	9.26	7.46
CO	0.00	1.12	0.06	0.05	0.03	0.002	0.31
	0.44	14.07	2.29	1.87	0.72	0.54	0.86
	3.59	147.1	16.28	29.38	3.25	3.17	2.55

Source: own findings

TABLE VII
COSTS OF THE REDUCTION OF 1 KG OF POLLUTANTS IN ACCORDANCE WITH THE ECO-99 RATIO METHOD [PLN/KG]

	1996	1998	2000	2002	2003	2004	2006
SO_2	0.31	3.25	5.37	3.94	0.38	0.84	21.08
	24.85	34.63	131.5	59.79	157.3	33.09	64.55
	123.1	85.45	1218	430.5	2296	191.0	195.0
NO_2	0.57	5.94	9.81	7.20	0.7	1.54	38.51
	45.39	78.95	1309	793.0	289.3	60.45	191.6
	0.57	5.94	9.81	7.20	4195	348.8	1445.
dust	0.59	6.26	10.24	7.59	0.74	1.62	40.61
	47.37	66.72	245.	115.2	88.28	63.76	124.4
	234.8	164.6	2323	829.4	465.0	367.9	2375
CO	0.00	0.04	0.07	0.05	0.01	0.01	0.27
	0.31	0.54	8.71	5.32	2.00	0.42	1.32
	1.55	4.01	177.9	160.6	28.94	2.4	9.97

Source: own findings

Reduction costs resulting from this method are equal for sulphur dioxide and nitrogen dioxide and are bigger than reduction costs for other pollutants, which, from an economic point of view, seem logical if we compare them to economic loss caused by air pollution. In the case of this method, we also observe a great discrepancy between minimum and maximum costs, which may be mainly caused by wrong decisions related to specific investments. It seems optimistic that, during the analysed years, average reduction costs dropped in comparison to previous years, but they did not reach the level of fees payable by companies for environment utilisation.

C. *Analysis of the Eco-99 Ratio Method*

The only method that does not show any disadvantages is the method based on the Eco-99 ratio.

Using this method, you may calculate unit costs for all analysed pollutants since there are impact values expressed in Eco-points for a wide range of polluting substances. This method also defines the most reliable toxicity ratios for analysed substances since they refer both to the environment as well as human life and health. These are not ratios representing predefined values like in the case of the NDS method or the fee method, but they are calculated on the basis of actual economic, social and environmental losses. In addition, the literature presents information about losses expressed in ECO-points, which could be compared with calculated values to confirm or question the rationality of analysed investments[16].

Costs of the reduction of 1 kg of pollutants in this method are quite high for all compounds as compared to previous results. This may be caused by the fact that these compounds actually cause significant economic, social and environmental losses, i.e. their toxicity for the environment is big. Minimum costs of the reduction of such substances are relatively small, however certain investments recording large investment expenditure increased the average cost of the 1 kg compound reduction. Based on the above results, it seems rational to adjust investments to unit reduction costs in order to avoid decision-making errors.

[16] Compare: Vigon B.W., Jensen A., (1995) *Life Cycle Assessment Data Quality and Databasis Protitione Survey, „Journal of Cleaner Production", 1995, No. 3.*

III. CONCLUSION

Environmental investments are called "specific investments" in the literature since they are subject not only to economic rules, but environmental rules focusing on society's interests, as well. Each investment reducing the emission of pollution is, from a social point of view, a necessary, profitable and even desired investment. However, from an economic point of view, the situation is different since investment expenditure borne to reduce the pollution plays an important role.

Independently of a method applied, the spread between minimum and maximum costs borne to reduce 1 kg of pollution in 1996 – 2006 was significant. Each of the analysed investments generated a tangible effect in the form of the reduction of a specific substance mass. From an economic point of view, the most rational investments were those where the biggest mass of reduced pollutants was obtained at the smallest investment expenditure. The above data show that not all of investments met such a criterion.

Particular presented methods applied to calculate pollution reduction costs reflected significant deviations in investment expenditure for the reduction of 1 kg of substances as a result of investments. This results from the fact that to calculate equivalent emission, various toxicity ratios were used. The problem discussed here, i.e. a question which of the methods reflects actual costs of the reduction of particular compounds in the most reliable manner, i.e. what the actual share of specific pollution reduction costs in total expenditure borne to reduce pollution as a result of investments is, was practically solved. In theoretical and empirical tests, the Eco 99-ratio method reflected both differences in particular pollution reduction costs, which confirms their different environmental impact, as well as referred to all analysed substances in the same manner as the only method.

To make decisions on environmental projects, financing institutions should take into account a rationality rule. Thus the Eco 99-ratio method could be applied to make decisions on environmental investments taken to protect the air.

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