

EX-ANTE ANALYSIS MODEL OF THE COST-EFFECTIVENESS OF ENVIRONMENTAL POLICY REGULATIONS

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Abstract

The paper aims to develop a model of ex-ante cost-effectiveness analysis for regulations applied in environmental policy. The experience gained so far in applying cost-effectiveness analysis on an ex-post and ex-ante basis has been analysed. Major problems have been identified in the practical application of the ex-ante cost-effectiveness analysis in non-investment activities. On this basis, a model for the ex-ante cost-effectiveness analysis was proposed. The developed theoretical model consists of three modules: data preparation, forecasting and interpretation. The model was verified on the environmental policy regulation – greenhouse gases emissions trading system which was implemented in Poland in 2008.

Keywords: Cost-effectiveness analysis; Environmental policy; Model.

1. INTRODUCTION

The economic effectiveness of environmental policy can be measured using several methods known in the source literature and quite well identified in theory, such as economic impact analysis, cost-benefit analysis, cost-effectiveness analysis, risk analysis or multi-criteria analyses. From an economic point of view, the best of these is a cost-benefit analysis. It allows for comparison in monetary units of all costs and benefits related to the implementation and operation of a given instrument. Unfortunately, despite its good theoretical basis, cost-benefit analysis is rarely used in practice. The problem is mainly related to external costs, which are difficult to identify and estimate. Above all, however, the valuation of environmental benefits is a barrier to the application of the analysis. Existing methods of environmental valuation require specialised natural and economic knowledge, which are time- and cost-consuming.

Therefore, the subject of the paper is the problem of measuring the cost-effectiveness of the environmental

policy. In this method of analysis of the environmental policy, environmental benefits occur in the form of specific environmental effects expressed in natural units. This is a major simplification compared to the cost-benefit analysis, and therefore the cost-effectiveness analysis is more frequently used in practice. So far, the analyses of the cost-effectiveness of environmental policy carried out worldwide have focused mainly on the evaluation of existing policies (ex-post analysis). However, it would be preferable to make extensive use of ex-ante analysis, which would allow the most cost-effective environmental policy solutions to be selected even before they are implemented. After all, this demand is still in the sphere of recommendations, mainly due to the lack of methodology of performing such an analysis. It is, therefore, necessary to develop a method that allows for the widespread use of ex-ante analysis in the process of environmental management.

The paper aims to develop a model of ex-ante analysis of the cost-effectiveness of environmental policy.

2. THE ESSENCE OF COST-EFFECTIVENESS ANALYSIS

Cost-effectiveness analysis was developed to measure the effectiveness of non-productive investments, i.e. investments whose effects are useful and often impossible to express in monetary units. This makes it difficult to ensure a uniform measurement of outlays and effects. In the case of outlays – money units are the measure, in the case of effects – these are natural units of different nature [1].

The cost-effectiveness analysis is carried out in several stages. Firstly, it is necessary to define the objective to be achieved. All possible ways (options) of achieving this objective and the levels of achievable impacts should then be identified. In the next step, the costs of implementation (and functioning) of each of the options to achieve the assumed objective are estimated. The last step is to assess the options considered and select the one with the lowest unit costs. Cost-effectiveness is usually expressed as the ratio of costs to effects.

However, cost-effectiveness does not indicate whether a measure is worth taking at all. It aims to

identify the one of the set of alternative undertakings (projects) which ensures that the lowest costs are incurred.

When deciding on cost-effectiveness analysis, it is necessary to establish as precisely as possible the environmental policy objective, i.e. the optimum level of pollution. Most often, this objective is set under conditions of uncertainty, without knowing the costs of reducing pollution and costs of avoiding environmental losses (environmental benefits) associated with achieving it. Assuming that the environmental policy objective is set at the right level, we can move on to considering how this can be achieved at the lowest possible cost.

The use of cost-effectiveness analysis in environmental policy is shown in Fig. 1. The key element of cost-effectiveness is to undertake the ex-ante analysis, even before the implementation of novel solutions. However, the ex-post analysis allows to identify various potential areas of efficiency improvement and thus it can serve to improve the ex-ante analysis – indirectly also increasing the cost-effectiveness of the measures taken.

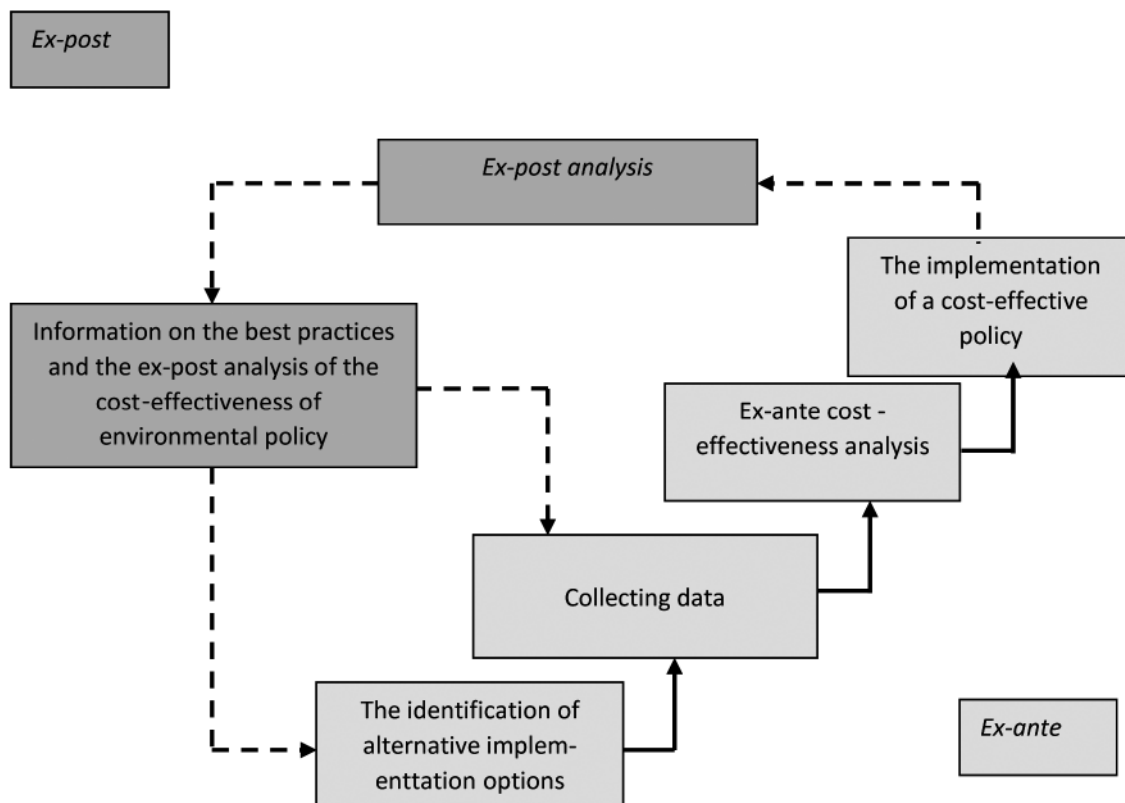


Figure 1.
The use of ex-post and ex-ante analyses in environmental policy. Source: own elaboration based on [2]

The model presented, in which ex-post analysis is the basis for ex-ante considerations, seems to be logically justified. Considering the stage character of the environmental policy, it is possible to imagine that the evaluation of the measures carried out at this stage (ex-post analysis) may be the basis for the ex-ante analysis of the measures planned for implementation in the following years.

The subject of economic analyses in the field of environmental protection has been taken up many times. In many textbooks and scientific papers, methods of economic assessment were presented, including policies, plans and strategies. In most cases, they focus on cost-benefit analysis, but also include cost-effectiveness analysis, e.g. [3, 4, 5, 6, 7 and 8]. These theoretical foundations were rarely reflected in empirical publications. Most of the works on cost-effectiveness concerned the area of health protection and not environmental protection. Based on the conducted analysis of the literature, it can be stated that several documents of a guiding nature have been elaborated around the world to assess the effectiveness of activities aimed at environmental protection. About 20 such items were identified from 1997 to 2016.

It should be noted, however, that despite the relatively considerable number of studies being prepared, most of them are of a general nature or treat the issue superficially. Cost-effectiveness analysis usually appears there as one of the methods of efficiency analysis, in addition to cost-benefit analysis and multi-criteria analysis. The approach to cost-effectiveness analysis is similar in the documents analysed. The differences mainly concern the technical aspects of carrying out the analysis, such as discounting, considering distributional effects or impact on competitiveness. However, the presented considerations concern a well-recognised document on ex-post analysis, Evaluating EU expenditure programmes [9]. The ex-ante cost-effectiveness analysis is considered to be a valuable tool to be applied “in the future”. While it is true that ex-post analysis is less important, it is often only used as a basis for ex-ante analysis.

The cost-effectiveness of ex-post environmental policy is required by law rather sporadically, despite that some measures taken and instruments implemented are very costly and should be subjected to cost-effectiveness checks. At the level of European Union law, several directives have introduced the obligation to carry out economic analyses. For example Water Framework Directive [10] – Annex III the Economic Study, Directive of 2001 on the promotion of electricity produced from renewable energy sources in

the internal electricity market [11] or Directive of 2001 on national emission ceilings for certain atmospheric pollutants [12].

Obligations to carry out ex-ante policy effectiveness reviews have found their place in EU legislation in several directives, mainly in the fields of soil and water protection, noise protection and the protection of natural resources. An example is Directive 2010/30/EU of 2010 on the indication by labelling and standard product information of the consumption of energy and other resources by energy-related products.

Among the member states, a reference to cost-effectiveness in legislation is made in the Netherlands (ex-post) and the United Kingdom (ex-ante). In the Netherlands, Article 20 of the Government Accounts Act states that ministers are responsible for the effectiveness and efficiency of policies. This includes carrying out regular checks on the effectiveness and efficiency of the policy. In the UK, the Green Paper on the evaluation of the central government states that all new policies, programs and projects require comprehensive evaluation, including a cost-effectiveness analysis [13].

3. THE IMPLEMENTATION OF THE COST-EFFECTIVENESS ANALYSIS OF THE ENVIRONMENTAL POLICY

The main challenge in analysing the cost-effectiveness of environmental policy is to discover the causal link between the observed effects and their causes and to include all necessary elements, as well as to separate the impacts of other factors. Problems with the collection of data for analysis are often emphasized, and this process is often time-consuming and costly. It is rarely specified how the effects and costs are to be monitored even before the start of the project.

The problem of the scale of the analysis is also signalled – traditionally, the analysis of cost-effectiveness was used to assess individual investment projects, and sometimes to assess local activities. The transfer of the analysis to a national or European level may increase its uncertainty [13].

In addition to the problems mentioned above, there is also the question of the type of costs to be included in the analysis. According to some economists, the financial costs traditionally used for analysis (investment outlays, and running costs) should be extended, for example, to include changes in producers' and consumers' incomes. Some economists report that

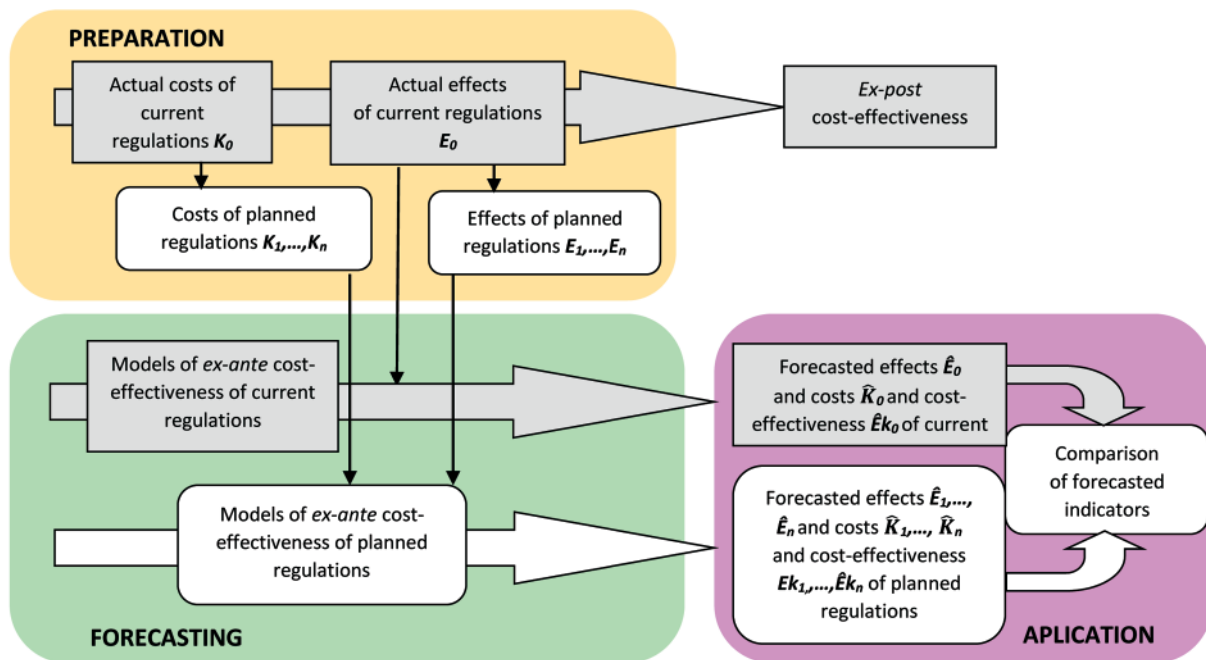


Figure 2.
The proposed model of ex-ante CEA of environmental policy. Source: own elaboration

social costs can be up to 30% of estimated policy costs and occur in all sectors of the economy, although regulations sometimes only apply to a few sectors [14]. To date, however, no study has been produced that considers the costs of policy in such a broad sense. The opposing voices concern the overestimation of costs. Harrington et al. [15, 16], after examining ex-ante analyses of environmental and occupational safety, concluded that the main reason for overestimating future costs was the inability to predict technological innovations. A spectacular example is the cost of SO₂ emission reduction, which in the Clean Air Act [17] was estimated at around 1500 \$/t, while in 1997 it amounted to around 75 \$/t. Another reason is that errors in the estimation of emission reductions or environmental effects are measured in other ways, which is also because technological developments are generally higher than assumed.

The issue of discounting the effects also arises. Cost discounting is standard in efficiency analysis. It is also asked in the literature: should the effects not be discounted, even though they are not expressed in monetary values? For example, if we compare two projects of equal cost-effectiveness, but in the case of the first one the objective will be achieved after two years, and in the case of the second one after five years, the first project should be chosen as more cost-effective.

The last issue concerns the manner of presenting environmental effects. They can be understood as the effects of reducing environmental pressures (e.g. tons of reduced emissions) or as the effects of impacts on the environment (e.g. avoided environmental damage or improved quality of environment). In practice, in most cases, the analysis focuses on assessing the pressure, as this is easier to measure, and above all, the causal link the measures and the effects are more obvious.

4. THE ASSUMPTIONS AND STRUCTURE OF THE MODEL

The proposed model for ex-ante cost-effectiveness analysis is an econometric model. The model consists of three main modules [18]:

Module I: Data preparation.

Module II: Forecasting.

Module III: Interpretation and application.

Figure 2 shows the main elements of this model and the relationship between them. The entire process boils down to comparing the forecasted value of the cost-effectiveness index of the current regulations of the national environmental policy with the value of the cost-effectiveness indexes of the planned new instruments of the ecological policy (module inter-

pretation and application). For this comparison to be possible, it is necessary to build cost-effectiveness models for those cases that reliably predict the value of indicators in the future. As models, econometric models have been proposed, based on which such a forecast is possible (module forecasting). Of course, in order to build models, it is necessary to collect relevant information (module data preparation).

The grey fields shown in Figure 2 refer to the current situation, the functioning environmental policy of the country with its instruments, measures, procedures, etc. When starting the analysis of cost-effectiveness, it is necessary to determine the historical values of the actual costs of the current regulations (K_0) and the actual effects of the current regulations (E_0). On their basis, possible changes in costs and effects that would occur after implementation of new regulations are determined, and possible costs of planned and possible costs of planned regulations and effects are determined ($K_1, \dots, K_n$ and $E_0, \dots, E_n$). Then, both for the actual situation and all variants of the new regulations, econometric models are built describing the relations between the effects and costs or their changes over time. The determination shall be made based on positively verified models:

- for the current regulations – the projected effects $\hat{E}_0$, costs $\hat{K}_0$ and cost-effectiveness $\hat{E}k_0$,
- for the planned regulations – the projected effects $\hat{E}_1, \dots, \hat{E}_n$, costs $\hat{K}_1, \dots, \hat{K}_n$, and cost-effectiveness $\hat{E}k_1, \dots, \hat{E}k_n$.

The last step in the model of *ex-ante* analysis of cost-effectiveness is to compare the obtained results and to select the option with the lowest costs of achieving the environmental objective.

The model also includes the position of a typical *ex-post* analysis of cost-effectiveness, which is the result of a comparison of the actual costs of the current regulations (K_0) and the actual effects of the current regulations (E_0) of the environmental policy. After the time for which the cost-effectiveness of the environmental policy was forecast, the *ex-post* cost-effectiveness analysis should be re-examined, and a comparison made with the forecast results obtained.

5. THE APPLICATION OF THE MODEL FOR EX-ANTE COST-EFFECTIVENESS ANALYSIS

The subject of the analysis is to compare the cost-effectiveness of environmental policy instruments aimed at reducing carbon dioxide emissions in Poland in 2020. The analysis was carried out on the basis of ex-post analysis of the cost-effectiveness of instruments. Two-time frames were distinguished, in which the climate protection policy used different sets of mechanisms:

- the first period, years 2002–2007, in which the instrument of emissions trading schemes did not function,
- the second period, 2008–2013, in which, apart from other legal, administrative and economic instruments, the instrument of emissions trading schemes functioned.

The entities included in the analysis are the large and medium-sized units classified in NACE, Rev. 2 as a section D – Electricity, gas, steam and air conditioning supply [19]:

35.11 – Production of electricity.

35.30 – Steam and air conditioning supply.

The second group of entities to be included in the analysis is public sector entities. The public sector was narrowed down to central offices, regional level offices and groups of offices directly related to environmental protection: voivodeship environmental protection inspectorates, regional environmental protection directorates, environmental protection, and water management funds. The public sector was included in the analysis as environmental management institutions, i.e. only concerning the costs incurred. Environmental effects in this sector are not the subject of analysis.

For reasons of access to information and reliability of data, the analysis is limited to direct costs. The following variables related to the protection of atmospheric air and climate were defined as the costs of achieving the environmental effect:

- in NACE units 35.11 and 35.30:
 - operating costs of environmental protection equipment (end-of-pipe and pollution prevention (integrated) equipment) – both on their own and the costs of services related to the operation of such equipment supplied from outside, costs of monitoring and control, and management costs,
 - charges for the introduction of pollutants into the air charges for trading in emissions of pollutants

- into the air,
- revenues and savings associated with the operation of environmental protection equipment,
 - subsidies received,
 - the depreciation of fixed assets;
 - in public sector units:
 - the costs of own activities and the costs of external services (excluding the operating costs of environmental protection equipment),
 - charges for the introduction of pollutants into the air,
 - revenues and savings associated with the operation of environmental protection equipment,
 - subsidies received,
 - revenues received for environmental protection services provided.

The source of data on the amount of the costs of atmospheric air and climate protection were the results of statistical research on the investment outlays for fixed assets for environmental protection and on the current costs of environmental protection. It was necessary to reach more detailed data than those presented in official statistics sources. At the same time, it was considered that the data source is reliable and the obtained data can be used for analysis.

The environmental effect – defined as the percentage reduction of carbon dioxide – is an example of the transformation of existing data into a form that is useful in this analysis. Existing data sources only provide information on CO₂ emissions. Therefore, the environmental effect in the form of a percentage reduction of carbon dioxide concerning the level of emissions in 1988, following the assumptions of the Kyoto Protocol was assumed (Table 1). The source of data on emissions were the reports of the The National Centre for Emissions Management, which can be considered as a reliable source of information.

Table 1.
The environmental effect

Detailed list	Year of analysis					
	I period of analysis					
	2002	2003	2004	2005	2006	2007
Environmental effect [% of CO ₂ reduction]	33.945	30.759	31.496	31.719	29.627	31.634
	II period of analysis					
	2008	2008	2008	2008	2008	2008
	33.988	33.988	33.988	33.988	33.988	33.988

Source: own elaboration

equivalent should be 20% of the 1988 emission value. As shown in Table 1, this objective has already been achieved. The focus should, therefore, be on reducing the unit costs of the CO₂ reduction level currently being achieved. In line with economic theory, the implementation of an environmental policy instrument, i.e. the greenhouse gases emissions trading system, leads to a reduction in the costs of achieving the environmental objective. The cost-effectiveness of such an instrument understood as unit pollution reduction costs shows a decreasing trend in subsequent years of the instrument's operation. The cost-effectiveness of the greenhouse gases emissions trading system can be recorded in the following form:

$$E_k = \frac{K}{E} \rightarrow \min, \quad (1)$$

where:

E_k – cost-effectiveness,

K – the total costs of achieving the economic goal in a million PLN,

E – environmental effect, understood as a percentage reduction of carbon dioxide, related to the level of emissions from 1988, which is the base year for the greenhouse gas reduction target ratified by Poland under the Kyoto Protocol.

The calculated value of cost-effectiveness concerning gross and net costs is presented in Table 2.

Table 2.
Cost-effectiveness of CO₂ reduction measures in the years 2002–2013 [million PLN/percentage of CO₂ emission reduction, related to the 1988 emission level], fixed prices in 2013

Analysis period	Year	Cost-effectiveness in relation to gross costs	Cost-effectiveness in relation to net costs
I period	2002	35.9693	35.1902
	2003	41.5068	40.6470
	2004	39.5434	38.7038
	2005	39.3764	38.5426
	2006	43.6976	42.6623
	2007	40.3013	39.4591
II period	2008	36.3873	35.6034
	2009	36.5995	33.7905
	2010	41.2125	38.1665
	2011	42.3502	39.2228
	2012	39.0837	36.0018
	2013	40.6166	37.0052

Source: own elaboration

The time horizon under consideration was 2020 when the reduction of greenhouse gases expressed as CO₂

5. ECONOMETRIC MODELS OF COST-EFFECTIVENESS

A model was searched for, which described the trend of cost-effectiveness in 2002–2007 (the first period of analysis) and 2008–2013 (the second period of analysis), but also the correlation between the magnitude of the environmental effect and the number of costs of its achievement. It was analysed:

- time series cost-effectiveness model,
- linearised non-linear cost-efficiency model,
- the linear regression model of the costs of achieving the environmental effect,
- a single equation linear econometric model for the ecological effect.

When building forecasts for longer periods, one should take into account the risk of changes in the model parameters over time. Making predictions assuming the stability of model parameters when in reality they are variable, may lead to serious systematic prediction errors. However, in order to simplify the analyses, the aim of which is not to examine the exact values of the forecast variables, but only to compare them in two variants, it has been assumed that the parameters will be constant in the period until 2020.

5.1. Time series modelling

The variable explained in the model is cost-effectiveness (Ek) and the only explanatory variable is time (t). Relationships between variables for both time series were assumed to be linear:

$$Ek_I = \beta_{0I} + \beta_{1I}t_I + \xi_I, \quad (t_I=1, \dots, 6) \quad (2)$$

$$Ek_{II} = \beta_{0II} + \beta_{1II}t_{II} + \xi_{II}, \quad (t_{II}=1, \dots, 6) \quad (3)$$

Time series were modelled separately as:

- cost-effectiveness in relation to gross costs, as a function of time in the first and second period,
- cost-effectiveness in relation to net costs, as a function of time in the first and second period.

Estimated models of the cost-effectiveness trend take the following form:

A. Cost-effectiveness in relation to gross costs:

$$\begin{aligned} \text{The first period:} \quad \hat{Ek}_{grI} &= 37.259 + 0.8019t \\ &\quad (2.1633) \quad (0.5555) \end{aligned}$$

$$\begin{aligned} \text{The second period:} \quad \hat{Ek}_{grII} &= 31.304 + 0.8496t \\ &\quad (4.8744) \quad (0.5050) \end{aligned}$$

B. Cost effectiveness in relation to net costs:

$$\begin{aligned} \text{The first period:} \quad \hat{Ek}_{nI} &= 36.478 + 0.778t \\ &\quad (2.0979) \quad (0.5387) \end{aligned}$$

$$\begin{aligned} \text{The second period:} \quad \hat{Ek}_{nII} &= 32.642 + 0.42t \\ &\quad (4.5637) \quad (0.4728) \end{aligned}$$

In order to verify the models obtained, the statistical significance of the model's estimated parameters was examined. For this purpose, the t-Student's test, determination coefficient R^2 , statistics F and critical materiality levels (p) were used. The obtained values did not allow for positive verification of the models.

5.2. Linearised non-linear regression

Selecting the functional form of the model, it was found that the function best describing the relation $Ek = f(t) + \xi$, is a hyperbolic function of the following form:

$$Ek_i = \alpha + \beta \frac{1}{t_i} + \xi_i, \quad (4)$$

where:

Ek_i – explained variable – cost-effectiveness,

t_i – explanatory variable – subsequent years of observation,

ξ – a random component.

Following the $\frac{1}{t_i}$ substitute z variable, the model becomes a linear model and as such can be estimated using the least squares method. The estimated functions for the analysed periods have taken the following form:

A. Cost-effectiveness concerning gross costs:

$$\begin{aligned} \text{The first period:} \quad \hat{Ek}_{gI} &= 42.52497 - 6.02251z_I \\ &\quad (1.37985) \quad (2.76766) \end{aligned}$$

$$\begin{aligned} \text{The second period:} \quad \hat{Ek}_{gII} &= 41.7622 - 5.84628z_{II} \\ &\quad (1.31695) \quad (2.64149) \end{aligned}$$

B. Cost effectiveness concerning net costs:

$$\begin{aligned} \text{The first period:} \quad \hat{Ek}_{nI} &= 41.598 - 5.871z_I \\ &\quad (1.33032) \quad (2.66832) \end{aligned}$$

$$\begin{aligned} \text{The second period:} \quad \hat{Ek}_{nII} &= 40.9686 - 39.8361z_{II} \\ &\quad (4.28446) \quad (38.6873) \end{aligned}$$

On the basis of the t-Student test, for most models (except for the cost-effectiveness model calculated concerning net costs in the second analysis period), the zero hypothesis (at the materiality level of 0.1) can be rejected, that the estimated parameter is not statistically significant.

The verification of the models was also carried out by determining the values of the F statistics and the corresponding probability p. The probability values for the first three models are below 0.1, which means that there are statistically significant parameters estimated. Also, the determination coefficients R^2 in the case of these models have higher values than in the cost-effectiveness model calculated concerning net costs in the second analysis period (Table 3).

Table 3.
The measures of matching and verification of linearised time series models of cost-effectiveness time series

Specification	Measurements of model fit and verification			
	R^2	The standard error of estimation	Statistics F	p
Gross Costs				
The first period	0.5421	1.939	4.7351	0.0952
The second period	0.5505	1.851	4.8985	0.0912
Net costs				
The first period	0.5475	1.870	4.8409	0.0926
The second period	0.2095	1.924	1.0603	0.3613

Source: own elaboration

Due to very poor matching of the cost-effectiveness model calculated concerning net costs in the second analysis period (the model explains only 19.91% of the variability of the explained variable), gross cost-effectiveness (calculated concerning gross costs) was selected for further analysis.

An analysis of normality of the rest was also performed with the Shapiro-Wilk test. The levels of test statistics $W_I = 0.8265$ and $W_{II} = 0.9621$ are higher than the critical value of $W_6(0.10) = 0.826$, so the rests can be considered to have a normal distribution. The normality of the distribution of the residuals is also confirmed by the probability values $p_I = 0.0999$ and $p_{II} = 0.8356$, which are higher than the assumed materiality level $p = 0.05$.

The gross cost-efficiency models of both periods have been verified positively, so they can be used for forecasting.

The year 2020 is interesting from the point of view of the cost-effectiveness of the market for transferable greenhouse gas emission allowances. After substituting the values of explanatory variables to the models of both analyzed periods, a forecast of the value of Ek^* in 2020 was obtained:

- the first period: $Ek^*_{I2020} = 42.208$ million PLN/% reduction in CO₂ emissions concerning the base year 1988, the interval forecast with a confidence level of 0.95 is (38.70; 45.72),
- the second period: $Ek^*_{II2020} = \text{PLN } 41.312$ million/% reduction in CO₂ emissions compared to the base year 1988, the interval forecast with a confidence level of 0.95 is (38.10; 44.52).

Relative *ex-ante* errors for 2020 were 5.48% in the first period, while in the second period 5.28% and in both cases they are below the 10% target. Therefore, the forecast presented can be considered admissible. According to the forecast, a country's environmental policy is more cost-effective when implementing the greenhouse gases emissions trading system than if this instrument had not been implemented. According to the hyperbolic model, the difference in cost efficiency in 2020 would amount to PLN 896.000 / % reduction in CO₂ emissions compared to the base year 1988.

5.3. Linear regression of one variable

The model of classical regression analysis was also applied, in which linear parameters were estimated using the method of least squares. The variable explained in this model is the gross cost of achieving the environmental objective, while the explanatory variable is the environmental effect.

The regression function was estimated separately for:

- gross costs, as a function of the environmental effect in periods I and II,
- net costs as a function of the environmental effect in period I and II.

Unfortunately, only one of the models has been positively verified. The estimated model for the first period and gross costs took the following form:

$$\hat{R}_{gI} = 1800.628 - 17.138E_I \quad (5)$$

(120.4238) (3.8161)

The value of the t-Student statistics for the explanatory variable E of -4.49094, with $p = 0.010898$ confirms that in this case, the environmental effect has a significant impact on the value of costs. Also, the value of F statistics = 20.169 at $p = 0.0109$ indicates the presence of statistically significant parameters in the model. In the case of this model, the determination coefficient R^2 assumed the value of 0.8345, which proves that the model was very well matched to real data.

Unfortunately, in other cases it was not possible to build reliable models, so the linear regression model of one variable was abandoned.

5.4. Single equation linear econometric model

In a single equation model of many variables, linear parameters were estimated using the method of least squares. The ecological effect was assumed to be the explanatory variable and the following variables were assumed to be explanatory variables:

- KFU_D – the costs of operation of security devices in units PKD35.1 and PKD35.2,
- $AMORT_D$ – depreciation in units of PKD35.1 and PKD35.2,
- $OPEL_D$ – ecological fees in units of PKD35.1 and PKD35.2,
- $KDW + ZPub$ – the costs of the public sector, understood as the sum of the costs of activities undertaken on their own and the costs of activities provided by external entities.

With the use of the step regression method, insignificant explanatory variables were eliminated from the model. Variables that are strongly correlated with the explained variable and poorly correlated with each other were classified as significant variables included in the model. These are KFU_D , $AMORT_D$, and $OPEL_D$ variables. The estimated model is therefore not affected by variables occurring in the public sector.

The estimated functions for the analyzed periods took the following form:

The first period:

$$\hat{E}_I = 126.8821 - 0.1142KFU_D - 0.1606AMORT_D$$

(10.4614) (0.0125) (0.0177) (6)

The dependence obtained shows that the increase in the operating costs of air and climate protection equipment by PLN 1 million results in a decrease in the environmental effect by 0.1142 percentage point, with constant amortisation. An increase in depreciation by PLN 1 million, with fixed operating costs of the equipment, results in a reduction of the environmental effect by 0.1606 percentage point.

The values of the t-Student statistics for the model of the first period were as follows:

- free word: $t = 12.12859$, at $p = 0.001206$,
- variable KFU_D : $t = -9.12077$, at $p = 0.002785$,
- variable $AMORT_D$: $t = -9.05217$, at $p = 0.002847$.

It can be concluded that the zero hypothesis of the lack of significance of the estimated parameters may be rejected, in favour of an alternative hypothesis, which proves the statistical significance of all parameters of the model.

The second period:

$$\hat{E}_{II} = 455.8563 + 0.0267KFU_D - 0.301OPEL_D - 1.43AMORT_D$$

(53.5714) (0.0062) (0.0373) (0.1882) (7)

The dependence obtained shows that the increase in the operating costs of air and climate protection equipment by PLN 1 million results in an increase in the environmental effect by 0.0267 percentage point, with the remaining variables remaining constant. An increase in environmental charges by PLN 1 million, with fixed operating costs of equipment and depreciation costs, reduces the environmental effect by 0.301 percentage point. Also, the increase in depreciation costs in the second analysis period by PLN 1 million (with other fixed variables) causes a decrease in the environmental effect by 1.43 percentage point.

The estimation of the functions of the environmental effect with negative parameters is confirmed by the relation, where the increase in the environmental effect is accompanied by a decrease in the costs of achieving the effect. It can be noted that the increase in the costs related to the protection of the atmospheric air had a lesser negative impact on the environmental effect in the second period rather than in the first period.

The values of t-Student's statistics for the model of the second period were as follows:

- free word: $t = 8.50933$, at $p = 0.01353$,
- variable KFU_D : $t = -4.33398$, at $p = 0.049332$,
- variable $OPEL_D$: $t = -8.07348$, at $p = 0.014998$,
- variable $AMORT_D$: $t = -7.59776$, at $p = 0.016886$.

Also, in the case of this model, the hypothesis that the parameters of the model are not statistically significant should be rejected.

Determination coefficients calculated for both models: $R_I^2 = 0.9653$ and $R_{II}^2 = 0.976$ indicate a very good fit for the estimated variables.

Also, the values of F statistics: in the first period: $F = 41.649$ at $p = 0.00648$ and in period II: $F = 27.252$ at $p = 0.03560$ indicate the presence of statistically significant parameters in these models. Measures of matching and verification of both models are presented in Table 4.

Table 4.
The measures of verification and matching of single equation cost-effectiveness models

Specification	The Measurements of model fit and verification			
	R ²	A standard error of estimation	F statistics	P
The first period	0.96524	0.34206	41.649	0.00648
The second period	0.97612	0.28694	27.252	0.03560

Source: own elaboration.

An analysis of normality of the rests was also performed with the Shapiro-Wilk test. The test coefficients S-W $W_I = 0.9691$ and $W_{II} = 0.9627$ are higher than the critical value of $W_6(0.10) = 0.826$, so the rests can be considered to have a normal distribution. Also, the probability levels $p_I = 0.8863$ and $p_{II} = 0.8403$ are greater than the assumed materiality level $p = 0.05$, which confirms the normality of the distribution of the residuals.

The models of both periods have been verified positively, so they can be used for forecasting.

The year 2020 is interesting from the point of view of the cost-effectiveness of the market for tradable greenhouse gas emission allowances. In the case of single-equation regression models, in order to forecast the explained variable, in the case under consideration – the environmental effect forecast E^* , the values of the explanatory variables should first be estimated. The linear and logarithmic function of trends (The models best suited to real data have been selected) has been used and the probable values of variables in 2020 (at 2013 prices) have been determined:

- $KFU_D_{I2020} = \text{PLN } 861.006 \text{ million,}$
- $AMORT_D_{I2020} = \text{PLN } 24.475 \text{ million,}$
- $KFU_D_{II2020} = \text{PLN } 1107.123 \text{ million,}$
- $OPL_D_{II2020} = \text{PLN } 76.228 \text{ million,}$
- $AMORT_D_{II2020} = \text{PLN } 298.89 \text{ million.}$

After adding explanatory variables to the models of both analysed periods, a forecast of E^* in 2020 was obtained as follows:

- the first period: $E^*_{I2020} = 24.66\%$ reduction in CO₂ emissions compared to the base year 1988, the range forecast with a confidence level of 0.95 is (21.00 %; 28.32%),
- the second period: $E^*_{II2020} = 35.12\%$ reduction in CO₂ emissions compared to the base year 1988, the

interval forecast with a confidence level of 0.95 is (33.83%; 36.40%).

The precision of these forecasts has been determined by the average error of prediction of the ex-ante score forecast for 2020. This is the largest possible forecast error for the period 2008–2013, as this error increases as we move away from the extinct forecast period. In the case of the forecast for period one, the absolute ex-ante forecast error amounted to 1.77 million PLN / % of CO₂ reduction, while the relative error was of 7.20%. The forecast error of the second period was lower – the absolute error amounted to 1.72 million PLN / % of CO₂ reduction, while the relative error was 4.91%. Errors within the range of 5–10% prove that the forecasts can be considered admissible.

6. THE INTERPRETATION OF THE RESULTS OF THE EX-ANTE COST-EFFECTIVENESS ANALYSIS

Among the econometric models developed above, the cost-effectiveness of greenhouse gas emission trade, two models were positively verified:

1. A linearized model of a time series.
2. A single equation model of the linear regression of many variables.

In the first case, cost-effectiveness was forecast calculated concerning total gross costs (both in the public sector, as well as in PKD 35.1 and PKD35.3).

As can be seen from the graph (Fig. 3) showing the development of cost-effectiveness for both periods, a lower cost-effectiveness ratio will be ensured for the functioning of the instrument, i.e. the market for greenhouse gas emission allowances.

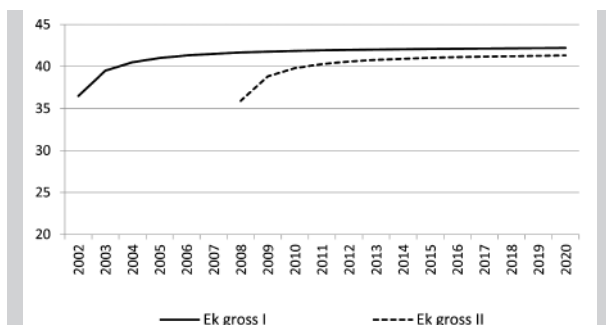


Figure 3.
Forecasted value of gross cost efficiency in 2020 in period I (2002–2007) and period II (2008–2013) [million PLN/% emission reduction compared to the base year 1998], fixed costs in 2013. Source: own elaboration

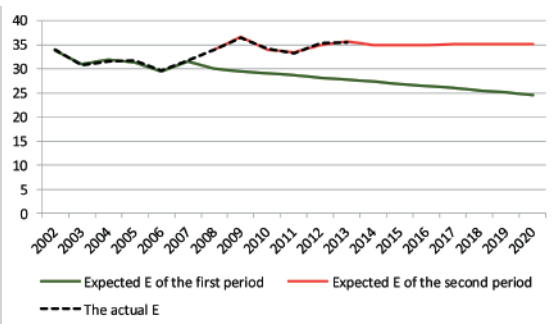


Figure 4.
The actual and projected value of the environmental effect in 2020 in period I (2002–2007) and period II (2008–2013) [percentage of emission reductions compared to the base year 1998]. Source: own elaboration

This is also confirmed by the result of the environmental effect forecast, obtained using the second model - a single equation model of many variables. In the case of this model, the subject of the forecast was the value of the environmental effect – Fig. 4.

The implementation in 2008 of trade in permits for emissions of pollutants introduced into the air allows maintaining the environmental effect in 2020 at the current (high) level. If this instrument had not been introduced, the environmental effect, expressed as a percentage of CO₂ reduction compared to 1988, could have been reduced.

Therefore, both econometric models confirm better cost-effectiveness of the national environmental policy in the field of atmospheric air and climate protection in the case of introduction of the analysing instrument of environmental policy. The cost-effectiveness indicators projected for 2020 – both a typical cost-effectiveness indicator (inputs/effects), as well as the projected environmental effect, assume more favourable values in the case of the application of greenhouse gases emissions trading system, in comparison to the mechanisms applied so far. An analysis of the reliability of the obtained forecasts will be possible after their expiry, i.e. after 2020.

7. CONCLUSION

The presented model of environmental policy regulation is a universal one and can be used for ex-ante analysis of the cost-effectiveness of various environmental policy areas. It seems to be the easiest to apply in those areas where quantifiable and measurable environmental effects exist, understood as the reduction of environmental pressure – the reduction of pollutants introduced into the air, the increase in the quantity or degree of treated wastewater, dispos-

al of more waste and the like. The model can also be useful for cost-effectiveness analysis of activities, where the effects are measured as the state of the environment in natural units, e.g. the emission of pollutants into the atmospheric air, parameters of water quality or quantity of pollutants in soil. Obviously, both in the case of pressure indicators and status indicators, reliable information on their levels is necessary. On the other hand, modelling cost-effectiveness is difficult if it concerns non-quantifiable or difficult to measure environmental effects, e.g. effects in the natural environment.

Further works on improving the cost-effectiveness analysis of environmental policies, both ex-post and ex-ante, should focus on broadening the scope of costs to be included in the analysis. In analysing example, external costs are not included in the calculation – this fact narrows the scope of applicability of the method and increases the uncertainty of estimates. Certainly, a cost-effectiveness analysis would be more valuable and closer to the truth if external costs could be included in the environmental calculations. In some cases, they may be higher than the direct costs included in the analysis and their inclusion could have an impact on the projected cost-effectiveness indicators of particular options of environmental regulations. The valuation of environmental external costs has been studied by economists for years. However, to date, the problem has not been solved to the extent that it allows the knowledge of the external costs to be used in the practice of making decisions in environmental policy.

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