# *Estimation of Gross Regional Product Losses Due to the Influence of Environmental Factors (in the Context of an Industrial Region)*

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***Abstract* — The scientific and methodological study of environmental pollution impacts on the gross regional product generation and the loss in the coal region is presented. Restrictions on the activities of the region's economic agents are given. Statistical data on people health/morbidity are cited. Evaluation techniques are given too. The multi criteria economic and mathematical model of the region in the form of multi-parameter linear programming problems is introduced. It contains control parameters for determination of such influence and includes environment component for the evaluation analysis including the interests of a producer, a consumer and a tax center of the region. This model allows the use of efficient algorithms for its numerical analysis (simplex method) for automated support of management decision-making for the development of different areas of the economic policy of the regional authorities. It is shown how the proposed model contributes to making informed management decisions at the regional level.**

***Keywords* — *ecological factors; environment; population health; gross regional product; the model of economic development of the region***

## INTRODUCTION

Due to the high rate of development of the coal industry, the environmental problems are greatly exacerbated. According to many researchers, the generation of the gross regional product (GRP) depends on the environment. This problem is mainly manifested in the regions with high population density and intensive development of such industries as coal mining, metallurgical, chemical, resulting in the significant impairment of land. The Kemerovo region can be classified as one of the most developed regions of the Siberian Federal District because of its raw material specialization. The coal industry is the leading sector in the region, which, together with the energy sector generates more than half of GRP which exceeds the similar average index both for the Russian Federation and for the Siberian Federal District.

### Influence of ecological situation on the generation of the Kemerovo Region GRP.

Coal mining enterprises occupy a large area on the territory of the region and represent many different sources of harmful effect on the environment. The negative consequences of their activities are pollution of air, land, water, location of mining dumps (topsoil disturbance). Coal companies have different impacts on the environment depending on the geological and geochemical properties of the deposit and the technologies used in the extraction of minerals.

The consequence of the increase in coal production is the increased rejection of fertile land. On average, one million tons of extracted coal account for up to 10 hectares of disturbed land. Note that about 60% of coal is mined by an open-pit method. The standard cost of new land opening-up in return for disturbed ones makes up to 1020 thousand rubles. In the period 2010 - 2014 years the area of disturbed lands has increased from 63.8 thousand hectares to 76.3 thousand hectares (19.6%) [1].

The main sources of air pollution from coal mining by underground methods are coal depots, waste rock dumps, ventilation shafts emitting methane by ventilation and degassing. A large amount of material flowing from the mines with a high content of coal leads to spontaneous combustion of waste heaps. The result is the emission of burning sulfur dioxide, carbon monoxide and tar sublimation products. The most significant source of dust and gas production polluting the air during the open mining operations is drilling and blasting operations that accompany different technological processes.

The consequences of a high degree of urbanization in the region, the development of high rates of the coal industry are the degradation of renewable natural resources including fertile soil layer, pastures, and the number of livestock. The most acute problem in the region is air pollution, which is estimated by the amount of gross emissions of pollutants into the atmosphere. According to this indicator, the region ranks the third in Russia and the second in the Siberian Federal District. The total amount of pollutant emissions into the atmosphere of the region in 2014 amounted to 1332.0 thousand tons, 488 kilograms per capita (Table 1).

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TABLE 1 Dynamics of pollutant emissions by industrial enterprises in relation to the branches of the Kemerovo region industry in 2010-2014.

| Emissions | 2010 | 2011 | 2012 | 2013 | 2014 | 2014 by 2010 (%) |
|---|---|---|---|---|---|---|
| In the whole region, thousand tons | 1411.0 | 1390.0 | 1360.0 | 1356.0 | 1332.0 | 94.4 |
| including the coal industry, thousand tons | 849.5 | 820.7 | 791.9 | 846.6 | 813.9 | 95.8 |

More than two hundred kinds of different substances are emitted in the atmosphere, most of which are highly toxic and carcinogenic, such as lead, soot, sulfur dioxide, carbon monoxide, nitrogen oxides, and hydrocarbons. The most common pollutants emitted from stationary sources are solids - 138 thousand tons, gaseous and liquid substances - 1194 thousand tons, including, sulfur dioxide - 101 thousand tons, nitrogen oxides - 63 thousand tons, carbon oxides - 259 thousand tons, hydrocarbons (without volatiles) - 756 thousand tons. [2]. Methane emissions are a serious danger. The use of methane as a fuel is the best way to reduce emissions of pollutants into the atmosphere.

The modern trend of regional economic policy orientation is characterized by the use of natural-resource potential, which allows one to develop such sectors as coal, iron and steel branches of the industry. Their development is economically justified and rational in terms of the survival of the regional economy and creates conditions for the stable functioning of the social sphere. At the same time, there are serious environmental problems that affect such an important component of the quality of life of the population, as health. Public health is an indicator of socio-economic situation in the country as a whole and in its individual regions. [3]

The quality of habitat affects the health of region's inhabitants and is traced by the dynamics of the population morbidity and mortality, which are the main problems for the Kemerovo Region. The natural population decline exceeds the birth rate (Table 2).

The number of population of the Kemerovo region in 2014 amounted to 2734.1 thousand people and fell to the level of 2010 by 38.9 thousand people (1.4%). The birth rate in 2014 compared to the pre-crisis year 2010 has increased by one thousand inhabitants. Mortality rate decreased from 16.6 deaths per one thousand people in 2007 to 14.6 cases per a thousand people in 2014. The average life expectancy increased to 67.85 years versus 66.1 years in 2010. The region is among the areas with high population density in the Siberian Federal District. The region accounts for 28.8 people per square kilometer. For comparison, the average number for the Siberian Federal District is 3.8, and in Russia - 8.4 [2, 4].

TABLE 2 The natural movement of the Kemerovo region population in 2010-2014.

| Indicators | 2010 | 2011 | 2012 | 2013 | 2014 |
|---|---|---|---|---|---|
| Population at the beginning of the year, thousands of people | 2773.0 | 2761.3 | 2750.8 | 2742.4 | 2734.1 |
| Birth rate (per 1000 people) | 13.1 | 12.7 | 13.8 | 13.6 | 13.2 |
| Mortality rate (per 1000 people) | 16.1 | 15.6 | 15.2 | 14.5 | 14.6 |
| Infant mortality rate (per 1000 people) | 8.3 | 7.4 | 8.8 | 7.3 | 7.2 |
| Natural population decline (per 1000 people) | -3.0 | -2.8 | -1.4 | - 0.9 | -1.4 |
| Life expectancy at birth, years | 65.42 | 66.19 | 66.76 | 67.72 | 67.85* |

*projected rate

In general, the demographic situation is characterized (as in most regions) by population decline due to low life expectancy, despite the fact that migration growth in the region in recent years is the highest in the Siberian Federal District and one of the highest in Russia. The main reasons are digestive diseases, respiratory diseases, tumors, infections (tuberculosis) and parasitic diseases, injuries, poisoning and accidents in the workplace and everyday life.

According to the Kemerovo regional committee of state statistics and the Kemerovo Regional Medical Information and Analytical Center, it is found that for the period of 2009 -2014 there is an increase in the overall morbidity by 3% and overall mortality by 10.5% in 2014. Infant mortality (number of infant deaths under 1 year old per 1000 births) is considered as one of the indicators of socio-economic development of the state and the society as a whole.

In the Kemerovo region, positive dynamics of reducing the infant mortality rate are observed, but, at the same time, the figure remains high. In many cases gradual growth of a variety of diseases and pathologies is caused by toxic effects on the mother's organism and fetus with different chemical compounds present in the atmosphere, reservoirs and other environmental objects. The main causes of mortality are congenital abnormalities, in which the main factor is the impact of the etiology of chemical substances and compounds, mutagenic and immunosuppressive effects on the child's body in the pre- and postnatal period. This pathology is considered to be the main indicator of the unfavorable state of the environment in the region.

Proceeding from the above-mentioned, one can conclude that the real environmental improvement is not observed and the effect of environmental factors on health status and, in general, the quality of life of the population is quite important in the region.

**The evaluation technique of the impact of environmental factors on the loss of GRP**

The negative impact of environmental factors on the health of the population results in an underproduced GRP. Table 3 shows the statistics on morbidity only by separate environment objects: water, air, which brings the Kemerovo region to 4 - 4.4% of GRP losses [2].

TABLE 3 Indicators for assessing the damage caused by population morbidity due to environmental factors, 2010-2014.

| Indicators | 2010 | 2011 | 2012 | 2013 | 2014 |
|---|---|---|---|---|---|
| Population, thousands | 2761.3 | 2756.0 | 2742.6 | 2742.4 | 2734.1 |
| GRP cost, billion RUB. | 622.5 | 763.5 | 717.1 | 668.3 | 695.0* |
| GRP, thousand RUB./people/year | 225.4 | 277.0 | 261.5 | 244.1 | 254.2 |
| Emissions, thousand tons | 1411.0 | 1390.0 | 1360.0 | 1356.0 | 1332.0 |
| Polluted waste water, mln.m$^3$ | 700 | 661 | 572 | 598 | 478 |
| Number of morbidity cases per 1000 people* | 1502.9 | 1573.0 | 1568.7 | 1620.0 | 1576.0 |
| Average number of man-days of illness * | 15.1 | 14.9 | 14.7 | 15.0 | 14.8 |
| Underproduced GRP cost million rub. | 25522.5 | 30540.0 | 28684.0 | 29712.7 | 30899.1 |
| GRP losses, % | 4.1 | 4.0 | 4.0 | 4.1 | 4.4 |

* According to the data of the Kemerovo regional medical information-analytical center GBUZ "KOMIATS"

In the presented data, the dependence of the underproduced GRP value on the population morbidity is traced. This leads one to conclude about the feasibility of developing automated tools (models, methods, and algorithms) for the analysis of this phenomenon.

Currently, there is no single methodology for assessing the impact of environmental factors on the morbidity and the quality of life, as there is no universal approach to the assessment of damage to national and regional economies because of the morbidity caused by environmental factors. Existing methods of evaluating macroeconomic environment pollution damages to health, in particular the use of the minimum and maximum levels of morbidity and mortality due to environmental factors, in our view, do not fully reflect the real situation [5, 6, 7].

In this study, the authors propose formal tools for assessing the impact of environmental factors on the loss of GRP, which are related to the working time losses due to morbidity, and are defined by levels of environmental pollution. This task is to be solved by using the model of economic development of the region. The activity efficiency criterion is maximization of GRP value based on incorporating environmental component of the interests of a producer, a consumer and a tax center of the region.

**Informative statement of the problem**

Consider the following informative statement of the problem of the environmental component impact of life quality on GRP. Let's us assume that there are three economic agents: a producer (P), a consumer (C) and a regional control (tax) center (T) operating and interacting in the region. The producer has the ability to organize production of n types of products (including innovation) in the region having bought (rented) basic production assets (BPA) - machines, equipment, buildings, land, etc. for n industrial enterprises of a separate sector (industries or areas of economic activity in the region, etc.). In this case, (C) receives livelihood (salary and insurance contributions to social funds) from (P) and spends it on its consumer basket (CB). (T) organizes interaction of (P) and (C) by collection of taxes, fees, fines, and redistribution of obtained financial resources in the form of grants between them.

It is assumed that (P) could produce products using polluting technologies, for which, according to certain rules, it is fined by (T), increasing by this the financial resources in the possession of (T). As the result of exposure to pollutants, (C) has increasing morbidity which leads to the loss of time and, accordingly, the increase in production costs (P) of labor payment and thereby in underproduced GRP cost. It is required to determine the level of GRP losses associated with the increased morbidity of (C), as well as the optimal investment (the amount of acquired BPA units) and production (the volume of revenue from sales of each type) characteristics of the project. The discounted net revenue and expenditure of ( P) and (C), as well as the discounted stream of tax (T) behind the planning horizon T are maximum, taking into account the interests and the natural limitations of each economic agent.

**Mathematical formulation of the problem**

Let ck be the average BPA cost of k-type, k = 1, ..., n, then Vk is average design BPA capacity of k-type; Tk - average BPA life of k-type; Pk – unit production cost of k-type; qk - expected cost demand for products of k-type; ξk, Dk - pollutant emissions (specific and maximum allowable respectively) in the production of a unit of production of k-type. Let R be total revenue from the sale of products, then Z is total general operating (depreciation, wages, taxes, raw materials, fines, etc.) costs. Let Am be accumulated depreciation deduction, then S0 is residual BPA value; Wb-balance profit; W - net profit; C0 – seed money; I - total investments; I0 - the maximum amount of investment. Let N1, N2, N3, N4 be value-added taxes (VAT), property tax (PT), profit tax (PT) and insurance premiums (IP) of plants (P), then N5 is overall environmental fine of the plants. Let α1, α2, α3, α4 be appropriate tax rates and fees, then α5 is penalties rate (the proportion of revenues from sales of products (P) determined by experts). Let Dot1, Dot2 be (T) grants to (P) (C), then β (labor intensity) is the share of total revenues from sales of products (P) entering the labor compensation fund. Let p (material consumption) be the proportion of the total cost (P) used for the purchase of raw materials, r is discount rate, and T - planning horizon.

Balance equations of the sums of actual funds of economic agents have the following form:

(P): $DP = W + Am + Dot_1$ ;

(C): $DC = C_0 + \beta R + Dot_2 - \sum_{k \in CB} q_k$ ;

(T): $DT = \sum_{i=1}^{5} N_i - \sum_{i=1}^{2} Dot_i$

**Restrictions on the activities of the region's economic agents**

First, suppose the solvency of the producer and the consumer: DP≥0, DC≥0. Terms of the limited amounts of investment I and subsidies can be written as follows:

(P): I≤I0, (T): $\sum_{i=1}^{2} Dot_i \le Dot_0$ .

The first condition limits the maximum amounts of investment (P), and the second - the maximum amount of subsidies of agent (T) to agents (P) (C). For the purposes of the problem, we have the following restrictions on the volume of production: value of production of each type at BPA performance, as well as the demand for it (in monetary form).

As the performance criteria of (P) (C) and (T) we consider the following indicators:

$$J_{(\mathrm{P})} = T \cdot \frac{W + Am}{1 + r_e}, \qquad J_{(\mathrm{C})} = T \cdot \frac{\beta R}{1 + r_e},$$

$$J_{(\mathrm{T})} = T \cdot \frac{N_1 + N_2 + N_3 + N_4 + N_5}{1 + r_e}.$$

It should be noted that these figures reflect the quality of the operation flow of the strategic (long-term) nature, manifested throughout the planning horizon of the regional project development, $r_e = \frac{rT}{1-(1+r)^{-T}} - 1$ - static discount project analogue of rate calculated for the entire planning horizon T.

Let xk be the average cost of basic production assets (investments) of k-type; xn + k - revenues from sales of products of k-type (k = 1, ... , n); x2n + 1 = Dot1, x2n + 2 = Dot2.

Then, $Am = \sum_{k=1}^{n} \frac{T}{T_k} x_k$, $R = \sum_{k=1}^{n} x_{n+k}$ – proceeds from the sale of all types of products; $S^0 = \sum_{k=1}^{n} \left(1 - \frac{T}{T_k}\right) x_k$ ; N2=α2S0.

Given this notation, the net profit (P) can be calculated by the formula:

$$W = (1-\alpha_3)\Big((1-p-\beta)R - Am - N_1 - N_2 - N_4 - N_5\Big)/(1-p)$$

, and the mathematical model of the problem to be solved becomes:

$$NPV_{(\mathrm{P})} = T \cdot \sum_{k=1}^{n} \frac{(-\gamma_k - 1 - r_e) x_k + \eta_k x_{n+k}}{1 + r_e} \to max \quad , \qquad (1)$$

$$NPV_{(\mathrm{C})} = T \cdot \sum_{k=1}^{n} \frac{\beta(1+\alpha_4) x_{n+k}}{1 + r_e} \to max \qquad (2)$$

$$NPV_{(\mathrm{T})} = T \cdot \sum_{k=1}^{n} \frac{\sigma_k x_k + \tau_k x_{n+k}}{1 + r_e} \to max \quad , \qquad (3)$$

$$\sum_{k=1}^{n} \gamma_k x_k - \sum_{k=1}^{n} \eta_k x_{n+k} + x_{2n+1} \le 0 \quad , \qquad (4)$$

$$\beta \sum_{k=1}^{n} x_{n+k} + x_{2n+2} \le C_0 - \sum_{k \in CB} q_k \quad , \qquad (5)$$

$$\sum_{k=1}^{n} \sigma_k x_k + \sum_{k=1}^{n} \tau_k x_{n+k} + x_{2n+1} + x_{2n+2} \le 0 \quad , \qquad (6)$$

$$x_{n+k} \le q_k \ (k = 1, ..., n) \quad , \qquad (7)$$

$$-\delta_k x_k + x_{n+k} \le 0 \ \ (k = 1, ..., n) \quad , \qquad (8)$$

$$\sum_{k=1}^{n} x_k \le I_0 \quad , \qquad (9)$$

$$\sum_{k=1}^{2} x_{2n+k} \le Dot_0 \quad , \qquad (10)$$

$$\alpha_5 \xi_k \frac{x_{n+k}}{P_k V_k} \le D_k \qquad (11)$$

$$x_k \ge 0 \ \ (k = 1, ..., 2n+2) \quad , \qquad (12)$$

where δk=(Pk Vk)/ck – return on assets of the Pension Fund of k-type;

$$\gamma_k = -\frac{T}{T_k} + 1 + \frac{1-\alpha_3}{1-p}\left(\frac{T}{T_k} - \alpha_1 + \alpha_2\left(1 - \frac{T}{T_k}\right)\right),$$

$$\eta_k = (1-\alpha_3)\left(1 - \frac{\beta + \alpha_1 + \alpha_4\beta + \alpha_5\xi_k}{1-p}\right),$$

$$\sigma_k = \alpha_1 - \alpha_2\left(1-\frac{T}{T_k}\right) + \frac{\alpha_3}{1-p}\left(\frac{T}{T_k} - \alpha_1 + \alpha_2\left(1-\frac{T}{T_k}\right)\right),$$

$$\tau_k = -\alpha_1 - \alpha_3 + \alpha_3\frac{\beta + \alpha_1 + \alpha_4\beta + \alpha_5\xi_k}{1-p} - \alpha_4\beta.$$

The built model (1) - (12) is a three-criterion linear programming problem. Its multi-criteria analysis is carried out by switching to an equivalent one-criterion problem with a convex linear combination of criteria [8] followed by a return to multi-criteria approach and construction of the Pareto-set. The model takes into account significant activity limitations of (P), (C) and (T) which do not allow the system to operate in critical conditions. In particular, provided are the conditions of solvency (4) - (6) of these economic agents, output limits being established by the demand for it (7), which exclude over-production crisis. In addition, the inequality (8) can be interpreted as an effectiveness limitation of BPA or the level of development of scientific and technical progress. Conditions (9), (10) reduce the volume of financial resources circulating in the system (investments and subsidies), and (11) - limits pollutant emissions by their maximum permissible values. For the decision-maker (DM), the main control tool to assess the loss of GRP due to the influence of environmental factors on the morbidity along with the parameters in (11) is a variation of the parameter β allowing automated calculation of the increase in the payroll cost (PC) resulting from the impact of this factor. In turn, the increase in the payroll affects the decrease in NPV (P) values correlated with GRP decrease.

The peculiar feature of the model is its optimization nature, allowing one to identify the economic potential activity of (P). This is an important argument in favor of its use when the current practice of pollution damage compensation in the form of environmental penalty is focused on the performance of the current financial statements of enterprises, whereby, performance indicators of enterprises in the interest of minimizing fiscal and environmental costs are often underestimated. With the use of the objective, automated tools of the economic potential (P) estimation can be the basis of effective management of the region's environmental policy in the interaction of (P), (C), and (T). Another feature of this model is its linear and static character that allows the use of efficient algorithms for its numerical analysis (simplex method) for automated support of management decision-making for the development of different directions of economic policy of the regional authorities. In particular, with the proposed model and adequate statistical basis, it is possible to solve the problem of evaluating the environmental components influence not only on the GRP, but also on the quality of life. Preliminary calculations carried out on the model initial data using the package [9] demonstrated the existence of the problem solutions by the described model (1) - (12).

## CONCLUSION

In the Kemerovo region, anthropogenic load and the morbidity rate exceed the national average more than twice. In addition, the rise of absolute and specific indicators characterizing the valuation of the impact of pollution on public health in the region and, as a consequence, on the GRP is observed. Assessment of damage to human health and the economy of the region provides the basis to public authorities to use it in the development of sustainable socio-economic development programs. Since a person is the primary productive force, the identified problems: damage to health, low life expectancy, resulting in population decrease can be regarded as damage to the region's future economy.

In summary, we note that the environmental factors have an impact on public health in the region, so that there is quite a high level of diseases, which entails the loss of the gross regional product. In this regard, the regional authority is faced with the question of development and adoption of urgent measures to improve the situation including the use of automated, objective, balanced assessment tool of costs balance evaluation to increase economic efficiency in the region and preserve the environment. These are, above all, measures to increase investments in fixed assets, environmental protection; improvement of methods of economic regulation in the field of environmental protection; replacement of outdated, environmentally dangerous technologies and equipment with modern environmentally friendly ones; introduction of non-waste technologies and recycling.

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