ECOLOGICAL AND ECONOMIC SECTOR INTERACTION MODELING WITHIN THE KYOTO PROTOCOL LIMITS FRAMEWORK

O.Voloshyn, V.Kudin, A.Onyshchenko

Abstract. *A modified ecological input-output model is proposed in the paper. Greenhouse gas emissions limits set on Kyoto Protocol were taken into consideration. The model productivity existence conditions that provide economic and environmental indicators non-negativity were found. The mathematical apparatus that in case of branch structure changes determines the change in the main and auxiliary industries gross output is considered.*

Keywords: *sustainable development, the Kyoto Protocol, an ecological and economic system, Leontief "input-output" model, Leontief-Ford "input-output" model, simulation modeling.*

ACM Classification Keywords*: I. Computing Methodologies – I.6. Simulation and modeling – I.6.5. Model Development –Modeling Methodologies.*

Introduction

Contemporary theoretical and practical economy prospective analysis demonstrates growing trend in consideration of social factors and life support on Earth on a global scale. This tendency is expected to be a major trend in terms of the global economy and to significantly determine international economic relations in the nearest future. In terms of world economy globalization and international economic relations, providing world society complete future is coming in the foreground. Therefore, consideration of environmental factors in macroeconomics has greatly increased. Furthermore, environmental component role, place and organisation were rased as a specific problem.

Therefore, developing a new conceptual approach to environmental resource as a current economic category becomes especially important. This new ecological and economic concept should be based on international economic relations, finding optimal ways for intergovernmental cooperation on environmental protection, resource conservation and low-waste technologies.

The Kyoto Protocol to the United Nations Framework Convention on Climate Change was the first intergovernmental agreement aimed to protect the environment by using economic instruments [KYOTO]. It was signed in 1997 by 84 states and establishes a procedure for greenhouse gases emissions reducing (primarily carbon dioxide). Their accumulation is recognized to be the cause of a major ecological problem - global warming. According to the Kyoto Protocol, the main polluters are industrialized countries. Therefore, they are committed to reduce the greenhouse gas emissions amount by 8% on the average compared to 1990.

The Kyoto Protocol also has international cooperation economic mechanisms. They declare that the climate effects do not depend on greenhouse gases emission locations and greenhouse gases concentrations in the atmosphere do not affect humans directly. These mechanisms are called "The Kyoto Protocol flexibility mechanisms" that refers to flexibility in choosing locations and facilities. The Protocol provides three economic mechanisms [Mechanisms].

International emission trading - the country obligation in not exceeding the set level of emissions for a particular reporting period. Each country is provided with national quotas on emissions. If the country does not use its quota fully, it has the right to emit an “extra part” to other countries.

"**Joint implementation" projects** - CO2 reduction cost varies for different countries. Thus, the country with quantitative commitments may finance projects on greenhouse gases reduction in another country with quantitative obligations. The resulting implementation of such projects are called "emission reduction units" and can be transferred to the investing party to offset its liabilities.

The clean development mechanism - countries with quantitative commitments are certified with emission reduction credits for financing projects related to the greenhouse gas emissions reduction in the countries without quantitative commitments.

Worlds’ community concern is stimulated by the real threat of a global warming and different countering prices in different countries. Reducing greenhouse gas emissions is a complicated process. Moreover, different conditions for their implementation and diverse effects on climate change vary from country to country. This makes a process of taking joint decisions ambiguous. For the first time, it is about creating a fundamentally new market sector, that directly affects the planet's atmosphere. It is clear that participants behavior rules and competition in this sector have features that require detailed analysis.

Implementation of the Kyoto Protocol requires a broad range of interdisciplinary sciences cooperation. Economic encouragement as a basic principle for solving environmental problems deserves particular attention. Studying the Kyoto Protocol economy requires an integrated and systematic approach [Voloshin, 2010].

Objectives

A number of issues related to state participation in the Kyoto Protocol, raises the need for environmental services market volume estimation, potential partners' identification and an economic strategy development that would identify priorities for each economic mechanism, their application proportions for the purpose of attracting environmental investments.

A special role in solving the fundamental problems of nature is environmental expenditures spendings justification. Taking into account the socio-economic impact and geographical distribution, these problems belong to input-output models as well as to regional and sectoral models.

Historically, the first and the simplest inter-sectoral industrial relations mathematical model was the Leontief's "input-output" model.

Let us put into consideration direct material costs coefficients matrix $A = (a_{ij})$, gross output column vector $X = (X_1, X_2, \dots X_n)^T$ and final production column vector $Y = (Y_1, Y_2, \dots Y_n)^T$. Here is the balance model in a matrix form [Leontief, 1986]:

$$X = AX + Y. \qquad (1)$$

The system of equations (1) is called an input-output economic-mathematical model (Leontief model).

The methodological basis for constructing balance models that take into account the environmental management serves as an expanded reproduction theory. At a present times the reproduction process, along with industrial relations, wealth and human resources reproduction necessarily includes natural resources and environment restoration.

An "input-output" model design and implementation based on environmental and economic balance scheme. It involves modern science fundamental problems solutions. The list includes development of reliable methods for predicting environmental parameters and its' quality criteria. They have to able to provide a quantitative measurement for human needs satisfaction level in a clean and natural diversity.

The list also includes creating science-based methods for determining the economic damage from pollution and modelling natural systems' various components interaction whereas taking into account natural and anthropogenic factors and conditions.

Thus, there is a need to build an environmental and economic model, that would include the Kyoto commitments implementation cost. Economic and environmental indexes nonnegativity raises the balance model productivity question. It is associated with technological matrix model. Changing the ecological and economic system sectorial structure is reflected in matrix coefficients and in turn it affects production volume and requires new algorithms development These algorithms have to define solution without solving the model equations.

Research results

The difficulty and factors variety in the national economy for greenhouse gas emissions reduction problems requires its deeper consideration in the context of existing production fields (economic activities). In leads to Kyoto Protocol implementation expenditure inclusion and pollution allocation among them. In this regard, we are considering greenhouse gas emissions limits costs in the structure of main production areas as:

$$\begin{cases} x_1 = A_{11}x_1 + A_{12}x_2 + Cy_2 + y_1, \\ x_2 = A_{21}x_1 + A_{22}x_2 - y_2, \end{cases} \tag{2}$$

where $x_1 = \left(x_1^1, x_2^1, \ldots, x_n^1\right)^T$ – production volumes column vector;

$x_2 = \left(x_1^2, x_2^2, \ldots, x_m^2\right)^T$ – destroyed pollutants volumes column vector;

$y_1 = \left(y_1^1, y_2^1, \ldots, y_n^1\right)^T$ – final products volumes column vector;

$y_2 = \left(y_1^2, y_2^2, \ldots, y_m^2\right)^T$ – uncompensated pollution volumes column vector;

$A_{11} = \left(a_{ij}^{11}\right)_1^n$ – square matrix of direct costs production coefficients i per production unit j;

$A_{12} = \left(a_{ig}^{12}\right)_{i,g=1}^{n,m}$ – rectangular matrix production costs i per destroying pollutants unit g;

$A_{21} = \left(a_{kj}^{21}\right)_{k,j=1}^{m,n}$ – rectangular matrix of pollutants release k per output unit j;

$A_{22} = \left(a_{kg}^{22}\right)_{1}^{m}$ $-k$ pollutants release per unit of destroying pollutants g square matrix.

Cy_2 – costs that are related to greenhouse gas emissions (ie greenhouse gas emissions maintenance costs, including a payment for allowances);

$C = \left(c_{ig}^{12}\right)_{i,g=1}^{n,m}$ – production costs i per unit of pollutant emissions g rectangular matrix;

In vector-matrix form model (2) can be represented as:

$$\begin{pmatrix} x_1 \\ x_2 \end{pmatrix} = \begin{pmatrix} A_{11} & A_{12} \\ A_{21} & A_{22} \end{pmatrix} \begin{pmatrix} x_1 \\ x_2 \end{pmatrix} + \begin{pmatrix} E_1 & C \\ 0 & -E_2 \end{pmatrix} \begin{pmatrix} y_1 \\ y_2 \end{pmatrix} \tag{3}$$

where E_1 and E_2 – identity matrixes.

The first equation reflects the economic balance - the industry's gross output distribution by primary and auxiliary production consumption, final consumption of primary production and costs associated with Kyoto Protocol commitments implementation. The second equation reflects the greenhouse gases physical balance as the emissions amount, resulting from the primary and auxiliary production activities of the main and auxiliary industries, and their uncompensated volumes.

The variable model (3) economic content requires nonnegative values consideration. This is closely linked to the balance model performance issue. This leads to the question of the production system functioning that can provide intermediate consumption, the final product positive production volumes and fulfillment of stated limits on greenhouse gas emissions.

In order to study solutions nonnegativity issue, let us express x_2 from the second equation and put it into the first:

$$x_1 = (E_1 - A_1)^{-1}\left(y_1 + Cy_2 - A_{12}(E_2 - A_{22})^{-1} y_2\right),$$

where $A_1 = A_{11} + A_{12}(E_2 - A_{22})^{-1} A_{21}$ – n-th order square matrix.

Let us also express x_1 from the first equation and put it into the second:

$$x_2 = (E_2 - A_2)^{-1}\left(A_{21}(E_1 - A_{11})^{-1} y_1 + A_{21}(E_1 - A_{11})^{-1} Cy_2 - y_2\right),$$

where $A_2 = A_{22} + A_{21}(E_1 - A_{11})^{-1} A_{12}$ – m- th order square matrix.

Thus, the formal solution of a system (3) can be written as:

$$\begin{pmatrix} x_1 \\ x_2 \end{pmatrix} = \begin{pmatrix} (E_1 - A_1)^{-1} & (E_1 - A_1)^{-1}\left(A_{12}(E_2 - A_{22})^{-1} - C\right) \\ (E_2 - A_2)^{-1} A_{21}(E_1 - A_{11})^{-1} & (E_2 - A_2)^{-1}\left(E_2 - A_{21}(E_1 - A_{11})^{-1} C\right) \end{pmatrix} \begin{pmatrix} y_1 \\ -y_2 \end{pmatrix}.$$

According to the methodology proposed in [Lyashenko, 1999, 2009], [Onyshhenko, 2011] let us generalize the “performance” concept in case of block matrices with nonnegative elements:

$$A = \begin{pmatrix} A_{11} & A_{12} \\ A_{21} & A_{22} \end{pmatrix} \geq 0. \quad (4)$$

We will assume that nonnegative block matrix is productive if the matrixes A_{11}, A_{12}, A_1 and A_2 are productive. Matrix A_1 and A_2 productivity means the main and auxiliary production profitability for the full production cycle and for the full greenhouse gas emissions destruction cycle. If matrixes A_{11}, A_{12}, A_1 and A_2 are productive, then the matrixes

$$(E_1 - A_{11})^{-1} \geq 0, \ (E_2 - A_{22})^{-1} \geq 0, \ (E_1 - A_1)^{-1} \geq 0, \ (E_2 - A_2)^{-1} \geq 0$$

exist and consist of nonnegative elements.

Block matrix (3) performance does not guarantee the system (3) solutions nonnegativity. Let us analyze the expressions for x_1 and x_2. From system (3) we obtain

$$x_1 = (E_1 - A_{11})^{-1}(A_{12}x_2 + Cy_2 + y_1).$$

It case that $x_2 \geq 0$, $y_1 \geq 0$, $y_2 \geq 0$ the condition $x_1 \geq 0$ is executed.

Thus, a necessity and sufficiency condition for nonnegative model (3) solutions in case of block matrix (4) productivity and at $y_1 \geq 0$, $y_2 \geq 0$ will be $x_2 \geq 0$ condition, that

$$(E_2 - A_2)^{-1}\left(A_{21}(E_1 - A_{11})^{-1} y_1 + A_{21}(E_1 - A_{11})^{-1} Cy_2 - y_2\right) \geq 0.$$

From the last inequality we obtain a sufficiency condition for the nonnegative solutions existence:

$$A_{21}(E_1 - A_{11})^{-1}(y_1 + Cy_2) \geq y_2,$$

that can be replace by even more strict sufficiency condition:

$$A_{21}(y_1 + Cy_2) \geq y_2.$$

The last inequality means that for main and auxiliary production functioning sufficiency condition is not exceeding the unutilized greenhouse gas emissions amount over the full greenhouse gas emissions. They are arising from the final product manufacturing and service costs that are held under the Kyoto Protocol.

Let us consider the problem of determining how the gross output and greenhouse gases utilization volumes vectors would change if technology matrix coefficients would change, including the environmental standards strengthening and the need to increase spending on Kyoto Protocol obligations fulfillment. For example, suppose that in the technological matrixes A_{11}, A_{12}, A_{21}, A_{22}, C one or more elements undergo changes.

Let us determine how the change affects the x_1 and x_2 vectors value. For this purpose, the procedure proposed in [Voloshin, Kudin, 2013, 2015].

The model (3) can be also represented as:

$$Au = C. \quad (5)$$

where $A = \begin{pmatrix} E_1 - A_{11} & -A_{12} \\ -A_{21} & E_2 - A_{22} \end{pmatrix} \begin{pmatrix} x_1 \\ x_2 \end{pmatrix}$, $u = \begin{pmatrix} x_1 \\ x_2 \end{pmatrix}$ – $(n+m)$ -dimensional vector, $C = \begin{pmatrix} E_1 & C \\ 0 & -E_2 \end{pmatrix} \begin{pmatrix} y_1 \\ y_2 \end{pmatrix}$, E_1, E_2 – corresponding dimension block unit matrixes, 0 – block zero matrix.

Let us also consider the system perturbations (in matrixes A_{11}, A_{12}, A_{21}, A_{22}, C elements) to linear algebraic equations system (5):

$$\bar{A}u = \bar{C}. \quad (6)$$

Where A , C - are corresponding perturbed matrix. Let us suppose that for the system (5) the basic solution and inverse matrix were found. Then there is the following theorem [Kudin, 2007].

Theorem 1. There are the following ratio for vectors normal restrictions expansion coefficients on matrix basic lines, inverse matrices elements, basic solutions and restriction residuals in two related basic solutions:

$$\bar{\alpha}_{rk} = \frac{\alpha_{rk}}{\alpha_{lk}}, \ \bar{\alpha}_{ri} = \alpha_{ri} - \frac{\alpha_{rk}}{\alpha_{lk}}\alpha_{li}, \ r = \overline{1, n+m}, \ i = \overline{1, n+m}, \ i \neq k. \quad (7)$$

$$\bar{e}_{rk} = \frac{e_{rk}}{\alpha_{lk}}, \ \bar{e}_{ri} = e_{ri} - \frac{e_{rk}}{\alpha_{lk}}\alpha_{li}, \ r = \overline{1, n+m}, \ i = \overline{1, n+m}, \ i \neq k. \quad (8)$$

$$\bar{u}_{0j} = u_{0j} - \frac{e_{jk}}{\alpha_{lk}}\Delta_l, \ j = \overline{1, n+m}. \quad (9)$$

$$\bar{\Delta}_k = -\frac{\Delta_l}{\alpha_{lk}}, \ \bar{\Delta}_r = \Delta_r - \frac{\alpha_{rk}}{\alpha_{lk}}\Delta_l, \ r = \overline{1, n+m}, \ r \neq k. \quad (10)$$

The matrix condition for being basis when entering the normal vector a_l restrictions $a_l u \le c_l$ for k-y basic matrix position A is the inequality fulfillment: $\alpha_{lk} \ne 0$.

Based on the reduced ratio we can build algorithmic scheme of study (6) (when the model has changes). The algorithm will be based on simplex method ideology [Voloshyn, Kudin, 2015], involving some iterative process features. In particular, the transition from the system (6) to the system (5) will be carried consecutively by relevant perturbed lines ($i, i+1, i+2, ..., i+i_0$) replacement.

This means that the normal vectors hyperplanes that form the basis matrix lines and the corresponding inverse matrix will be replaced by appropriate "perturbed" normal vectors. Following basic solutions and inverse matrixes will be recalculated based on simplex relations (7)-(10). While maintaining the basic properties on replacement iterations, system (6) solution would be found by i_0 iterations. The result is a new base solution and the inverse matrix.

Based on the following information we can present a new algorithm for new solution determination in case of the basic matrix elements perturbation. This approach allows to determine changes in the gross output volume when ecological and economic model (3) technological matrixes were changed.

Step 1. Let us find the initial system (5) solution and the inverse block matrix A^{-1}.

Step 2. Matrix A undergoes perturbation in a_{kj} element: $\bar{a}_{kj} = a_{kj} + a'_{kj}$.

Step 3. Let us determine the coefficient $\alpha_{ek} = 1 + a'_{kj} \cdot e_{jk} \ne 0$, where e_{jk} – corresponding element for matrix A^{-1}.

Step 4. Let us find the new column vector $\bar{e}_k = \dfrac{e_k}{\alpha_{ek}}$ for matrix A.

Step 5. Let us determine the residual for the element perturbed line: a'_{kj} : $\Delta_e = \bar{\Delta}_k = a'_{kj} \cdot u_{0j}$, where u_{0j} is a j-th component for u_0.

Step 6. Let us find a new solution based on the following correlation: $\bar{u}_0 = u_0 - \bar{e}_k \cdot \Delta_e$.

Let us illustrate on conditional data the proposed algorithm in case of technological inter-branch changes. Let the ecological and economic model (3) technological matrix coefficients have the following values:

$$A_{11} = \begin{pmatrix} 0.2 & 0.1 \\ 0.3 & 0.2 \end{pmatrix},\ A_{12} = \begin{pmatrix} 0.1 & 0.2 \\ 0.2 & 0.2 \end{pmatrix},\ A_{21} = \begin{pmatrix} 0.1 & 0.3 \\ 0.2 & 0.3 \end{pmatrix},\ A_{22} = \begin{pmatrix} 0.2 & 0.3 \\ 0.3 & 0.1 \end{pmatrix}.$$

Greenhouse gas emissions maintenance costs matrix, sectoral final release vector and greenhouse gas emissions restrictions vector respectively:

$$C = \begin{pmatrix} 0.3 & 0.2 \\ 0.1 & 0.5 \end{pmatrix},\ y_1 = \begin{pmatrix} 12 \\ 23 \end{pmatrix},\ y_2 = \begin{pmatrix} 5 \\ 8 \end{pmatrix}.$$

Let us verify the performance condition for ecological and economic system in the case of numerical data. Block matrix A

$$A = \begin{pmatrix} 0.2 & 0.1 & 0.1 & 0.2 \\ 0.3 & 0.2 & 0.1 & 0.2 \\ 0.1 & 0.3 & 0.2 & 0.3 \\ 0.2 & 0.3 & 0.3 & 0.1 \end{pmatrix}$$

is productive because it is sufficient as a technological matrix for Leontiefs' type balance models. We should also note that model (3) performance is sufficient what is proven by inequality $A_{21}(y_1 + Cy_2) \geq y_2$:

$$\begin{pmatrix} 9.76 \\ 11.27 \end{pmatrix} \geq \begin{pmatrix} 5 \\ 8 \end{pmatrix}.$$

Here is the algorithm steps 1-6.

1. Let us find the system solution and the inverse technology matrix: $u_0 = \begin{pmatrix} 38.17 \\ 60.43 \\ 32.67 \\ 30.62 \end{pmatrix}$,

$$A^{-1} = \begin{pmatrix} 1.79 & 0.73 & 0.6 & 0.76 \\ 1.08 & 2.0 & 0.74 & 0.93 \\ 1.04 & 1.32 & 1.99 & 1.19 \\ 1.1 & 1.27 & 1.04 & 1.99 \end{pmatrix}.$$

2. We assume that in model (3) $a_{21}^{11} = 0.3$ element undergoes perturbation. It increases for 0.1. This means second field production costs increase per unit of the first sector. Therefore, $\bar{a}_{21} = 0.3 + 0.1 = 0.4$.

3. Let us find $\alpha_{lk} = \bar{\alpha}_{kk} = 1 + 0.1 \cdot a_{12}^{-1} = 1 + 0.1 \cdot 0.74 = 1.074$.

4. Let us determine the column vector: $\bar{e}_2 = \begin{pmatrix} 0.73 \\ 2.0 \\ 1.32 \\ 1.27 \end{pmatrix} / 1.074 = \begin{pmatrix} 0.68 \\ 1.86 \\ 1.23 \\ 1.18 \end{pmatrix}$.

5. Let us calculate perturbed line residual: $\Delta_l = \bar{\Delta}_2 = 0.1 \cdot 38.17 = 3.817$.

6. The new solution is obtained: $\bar{u}_0 = \begin{pmatrix} 38.17 \\ 60.43 \\ 32.67 \\ 30.62 \end{pmatrix} - 3.817 \cdot \begin{pmatrix} 0.68 \\ 1.86 \\ 1.23 \\ 1.18 \end{pmatrix} = \begin{pmatrix} 35.57 \\ 53.33 \\ 27.97 \\ 26.12 \end{pmatrix}$.

Solution analysis brings us to the following conclusions. In terms of the ecological and economic system (3): second branch unit release costs increase for one first branch unit leads to a 1st and 2nd material production gross output decrease by 2.6 and 7.1 standard units respectively. It also leads to greenhouse gas volume utilization decrease of 1st and 2nd type for 4.7 and 4.5 standard units respectively.

Conclusion

In the modern civilization system there is a need to take into account environmental factors. This causes further production activities consideration within a single socio-ecological-economical system. An important requirement for its existence is the need to balance between the interests of these subsystems. An effective tool is a balance method and corresponding methods, such as a model proposed in this article. It takes into account costs for projects aimed to reduce greenhouse gas emissions.

Performance conditions and determining the total industrial releases volume algorithm in case of technological branch structure changes were established for model effectiveness. Further studies would be appropriate in the field of additional economic and environmental constraints inclusion as well as changes in classical assumptions about the technological structure of the proposed model.

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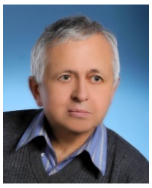

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