MODELLING OF THE INFLUENCE OF ENERGY-SAVING TECHNOLOGIES ON THE DEVELOPMENT OF THE UKRAINIAN INDUSTRIAL REGION

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The estimate of the influence of investing in energy saving of sectors on the development of the industrial region on the basis a dynamic input-output model is considered in this paper. The model includes nonlinear investment functions, which characterize the dependence structure of the current inputs of the regional economy from investment in energy-saving technologies, taking into account the time lag between investments and returns from them. The choice of the most effective trajectory of the economic development of the Donetsk region for different variants of investing in energy-saving technologies of key industrial sectors is substantiated using this input-output model

INTRODUCTION

One of the main problems of Ukrainian economy is significant energy intensity of the gross national product (GDP). According to the International Energy Agency, in Ukraine this indicator is 2.6 times as much the average energy intensity of GDP in advanced countries. Energy intensity of the national heavy industry, which ensures the largest foreign currency earnings, is 10 times as much this indicator in Western Europe. At the same time, Ukraine is the energy-scarce countries, which covers own energy consumption by about 53%. As notes Ministry of Energy and Coal Industry of Ukraine, Ukrainian enterprises import 75% of the natural gas and 85% crude oil and petroleum products. The stable trend of increasing in energy recourses' prices worsens that situation.

For solving this problem, it is necessary priority investments in energy-saving technologies of main sectors of the industrial regions as the basis of the Ukrainian economy. A dynamic input-output model is convenient tool for analysis of alternative investments in energy efficiency of sectors for choosing the most effective variant the development of the industrial region's economy.

2. RESEARCHING THE SECTORAL ENERGY INTENSITY OF THE ECONOMY BY APPLYING THE INPUT-OUTPUT ANALYSIS

Using input-output tables and models for analyzing changes of sectoral energy intensity of the economy and the substantiation of its reduction options is discussed in many research studies such as Mikhalevich M. and others (1998); Ghebremedhin T. and Schreiner D.; Rathin B. (2002); Fujikawa K. and others (2006); Cuihong Y. and Chunlin Y. (2007); Sathaye J. and Gupta A. (2010); Moradkhani N. (2011). A number of researchers study the impact of the different factors that reflect structural changes of the economy on the expected changes of sectoral energy intensity, as a rule based on a long-term time series input-output table database. The analysis of these researches shows: despite the significant impact of a final demand and its structure on the efficiency of energy intensity, the most important factor of a reduction of real energy intensity is changes in sectoral technologies.

Indeed, as note Sathaye J. and Gupta A., since the energy intensity usually characterizes how much energy was used to produce per unit GDP, the nominal value of this indicator may be reduced: for example, if the growth rate of energy consumption in monetary terms is lower than the growth rate of prices for goods and services or the deflator. The reduction of the real value of this indicator occurs only when the share of energy cost in the whole production cost is reduced, which usually involves using a new technology of production.

This is a particularly important issue for industrial countries, because the industrial sector is characterized by the significant energy intensity among all sectors of the economy. In a study concerning the reduction of the vulnerability of the industrialized countries to the changes in the price of natural resources due to the progress of resources saving technologies, Fujikawa K. and others observe that the efficiency of this process depends substantially on the adoption of energy-saving technologies for sectors that import energy.

It is important to use input-output analysis for substantiating the best alternative choice among the set of admissible alternatives. One of these approaches is considered by Ghebremedhin T. and Schreiner D. They present the development of a comprehensive energy information system and the integration of this information into a dynamic simulation model for purposes of evaluating alternative energy choices. At first, the output for so-called «non-energy sectors» is estimated. Then these sector output estimates are utilized for projecting state economic variables, and projecting state energy requirements and trade by energy source. Finally, impact analysis compares alternative growth rates in energy production and efficiencies in energy utilization with baseline projections.

The estimate of the sector output is based on a static input-output model. Technological efficiency in energy use and the distribution of energy use by source are assumed constant for the projected period.

Of a special interest is the study of the way structural changes, which are associated with increased technological efficiency of energy use, influence the economy, using input-output models. At the same time, the optimal changes in technological coefficients can be found in compliance with a specified optimization criterion. In particular, these studies were carried out in the V.M. Glushkov Institute of Cybernetics of NAS of Ukraine, under the leadership of Mikhalevich M. Sergienko I., Mikhalevich M. and others present a static input-output model that uses to optimize the input-output coefficient primarily by reducing the energy use per unit sector output. The optimization criterion chosen is one that maximizes the real incomes of consumers, which are estimated on the basis of added value, taking into account the structure of consumption for sectors.

As a rule, structural changes in the economy resulting from increased technological efficiency of energy use are realized by investments in energy-saving technology of sectors. Dynamic input-output models are a convenient tool for assessing how an economic development depends on structural changes in the economy as a consequence of the influence of investment flows. The addition of alternative technologies in the input-output model allows one to estimate different trajectories of balanced proportional development of the economy at a given time. If the goal of research is not only predicting a possible choice of an economic development but also finding the best of them, this problem is solved using an optimization model, and it is necessary to determine the optimization criterion.

In this paper, a discrete dynamic input-output model is considered as a tool for substantiating the best trajectory of the economic development of the Ukrainian industrial region for different variants of investment in energy-saving technology. In considering the problem of choosing this trajectory, we note that the effective economic development is characterized both by the steady growth of a gross output as a result of the investment in sectoral technologies and by the growth of funds that are used for a final consumption. Taking into consideration that the growth of investments leads to further sustainable economic growth and that the growth of consumption is regarded as improving social welfare; it is necessary to determine what amount of funding we need to invest for the maximization of social welfare for a given time. Therefore, in our opinion the best trajectory of economic development is the one that gives “investment-consumption” proportion for the chosen variant of investing in energy efficiency so that final consumption would be maximized for a given time.

3. THE MODEL OF THE CHOICE TRAJECTORY OF DEVELOPMENT OF THE INDUSTRIAL REGION TAKING INTO ACCOUNT INVESTING IN ENERGY-SAVING TECHNOLOGIES

We use a dynamic input-output model for an estimate of the influence of sectoral investment in energy-saving technology on the efficiency of the economic development of the industrial region:

$$X_t - A_t X_t - B_{t-1}(X_t - X_{t-1}) = Y_t, t = \overline{1,T}, \qquad (1)$$

where X_t – vector of gross output with dimension n in year t;

A_t – matrix of input-output coefficients (current inputs) with dimension ($n \times n$) in year t;

B_{t-1} – matrix of capital coefficients with dimension ($n \times n$) in year $t-1$;

Y_t – vector of final demand with dimension n in year t;

T – planning period.

We introduce the following simplifying assumptions:

1. The regional economy is considered as a closed system, which provides its own growth only at the expense of domestic investment, the source of which is the final demand.

2. The final demand consists of two components - investment and consumption:

$$Y_t = I_t + C_t, t = \overline{1,T}, \qquad (2)$$

where Y_t – vector of final demand in the year t;

I_t – vector of investment in the year t;

C_t – vector of consumption in the year t.

3. The value of the final demand at the initial point of time depends only on the initial value of gross output and intermediate demand structure:

$$Y_0 = (I - A_0)X_0, t = \overline{1,T}, \qquad (3)$$

where Y_t – vector of final demand in the year $t=0$;

I – identity matrix;

A_0 – matrix of input-output coefficients in the year $t=0$;

X_0 – vector of gross output in the year $t=0$.

4. Matrix A and B are constant for the basic alternative of assessment of the regional development dynamics. For assessment of the development taking into account the energy saving, the elements of the matrix A, which reflect the energy

consumption sectors of the regional economy, vary depending on the value of sectoral investment in the initial point of time:

$$a_{ij}^{t} = f(I_j^{t-1}), i, j = \overline{1,n}, t = \overline{1,T}\ , \tag{4}$$

where a_{ij}^{t} – input-output coefficient, which characterizes the use of product of sector *i* per unit of product of sector *j* in year t*;*

I_j^{t-1}– investments in energy-saving technology for sector *j* in year *t-1*.

Let us formulate the problem of the choice of the most effective trajectory of development of the industrial region taking into account investing in energy-saving technologies of sectors.

Let $T = \langle T_1, T_2, ...T_k, ..., T_K \rangle$ – set of planning periods;

$r = \langle r_1, r_2, ..., r_s, ..., r_S \rangle$ – set of methods of investment allocation consisting of final demand;

$I = \langle 1, 2, ..., v, ..., V \rangle$ – set of investment variants.

Need to find of the best trajectory of regional economic development for a given planning period, according to the criterion of maximizing the efficiency of regional development:

$$E^{*} = \max_{v \in I} E_{SER}^{v} \text{ for } T = T_k\ , \tag{5}$$

where E_{SER}^{v}– an indicator of the efficiency of regional economic development for the chosen variant of investing in the sectoral technology, which is determined by maximizing the annually averaged final consumption:

$$E_{SER}^{v} = \max_{r_s \in r} \overline{C}^{v}(r_s, T_k) = \max_{r_s \in r} \frac{\sum_{t=1}^{T_k} \sum_{i=1}^{n} c_{it}^{v}(r_s)}{T_k} \text{ for } \forall v \in I \tag{6}$$

where $\overline{C}^{v}$ – annually averaged final consumption for investment variant *v*;

r_s – share of investment in the final demand;

T_k – planning period.

Final consumption is estimated using a dynamic input-output model at every point of time within a given planning period, based on the assumption that the final demand consists of two components - consumption and investment (see the simplifying assumption (2)):

$$C_t^v = [\, X_t^v - A_t^v X_t^v - B\Delta X_t^v \,] - I_t^v, t \in T_k \,, \quad (7)$$

where C_t^v – vector of final consumption for the investment variant v in year *t*;

X_t^v – vector of gross output for the investment variant *v* in year *t*;

I_t^v – vector of investments for the investment variant *v* in year *t*;

A_t^v – matrix of input-output coefficients in year *t* for the investment variant *v* in year;

B – matrix of capital coefficients.

This takes into account the following restrictions:

for the possible limits of sectoral costs variation due to the features of existing technologies:

$$\underline{a_{ij}} \le a_{ij} + \Delta a_{ij} \le \overline{a_{ij}} \,, \quad (8)$$

where $\underline{a_{ij}}, \overline{a_{ij}}$ – the lower and upper restriction of the existing input-output coefficients accordingly;

Δa_{ij} – increase the input-output coefficient due to investments in new technology;

for the share of investment in the final demand:

$$\underline{r_s} \le r \le \overline{r_s} \,, \quad (9)$$

where $\underline{r_s}, \overline{r_s}$ – the lower and upper restriction of share of investment in the final demand accordingly.

4. THE ESTIMATE OF THE TRAJECTORIES OF THE ECONOMIC DEVELOPMENT OF THE INDUSTRIAL REGION USING THE DINAMIC INPUT-OUTPUT MODEL

4.1 The estimate of the trajectories of the economic development without of investment in energy saving (base variant)

These estimates of the trajectories of the economic development are calculated for the Donetsk region which is one of the largest Ukrainian industrial regions. At first, using the dynamic input-output model (5)-(9) and establishing simplifying assumptions, we estimate the influence of investing in the economic development of the Donetsk region for the base variant ($v = 0$). This variant does not include investing in energy saving, so input-output coefficients do not change over the whole planning period.

The matrices *A* and *B*, which are a base of modeling estimates, are constructed using statistical reporting data of the Donetsk region's enterprises given by the Donetsk Regional Department of Statistics. These matrices satisfy the mathematical conditions for correct calculations by the dynamic input-output model.

Set of trajectories of the economic development of the Donetsk region are calculated based on formulas (1) and (7) for the different methods of investment allocation consisting of final demand (investment rate) $r_s = 10\ \%, 20\ \%, \ldots, 90\ \%$. The trajectories of growth of the final demand Y_t are represented in Figure 1. These trajectories characterize the influence of increasing investment on this indicator. However, it is important to estimate the influence of investment on the dynamics of the final consumption as a share of the final demand because the growth of the final consumption by itself characterizes the growth of social welfare in the region (see the formula (6)).

The graphs in Figures 2, 3 reflect that the dependence of the final consumption from the investment rate is such that starting from some value of r_s, the consumption starts to decrease.

FIGURE 1. Final demand for different investment rates

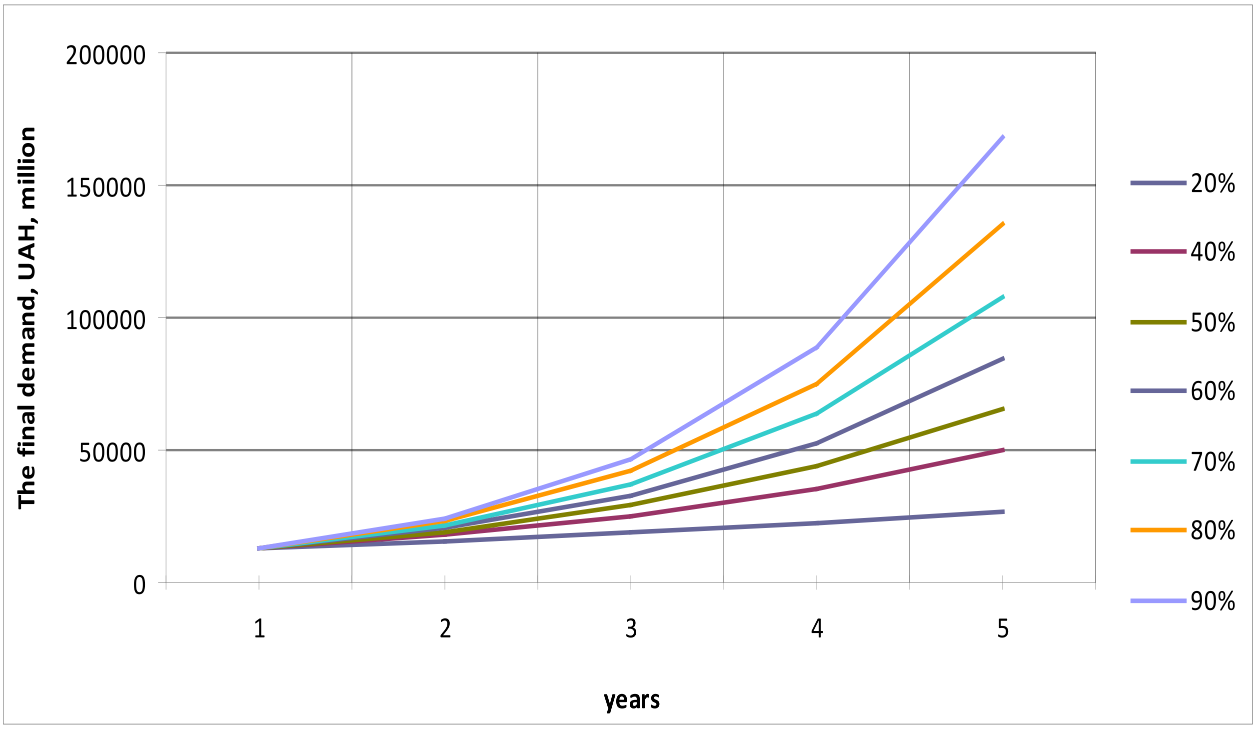


FIGURE 2. Final consumption for different years of planning period (1 – 4 years)

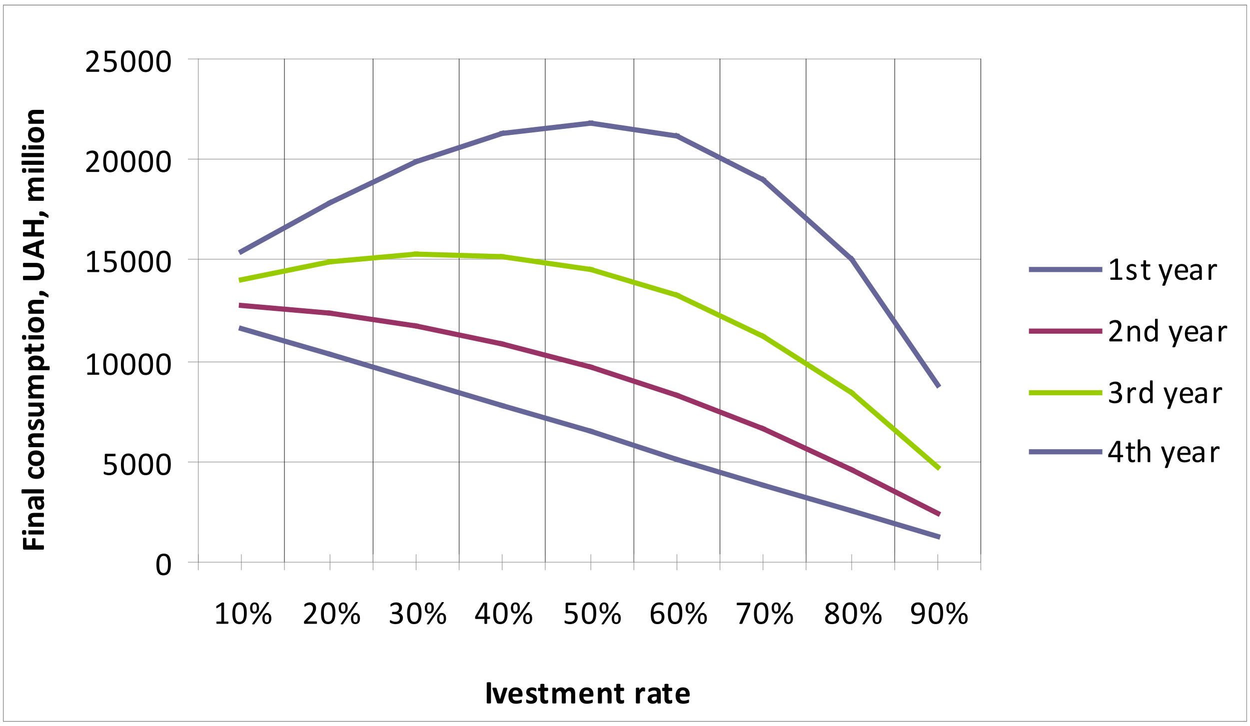
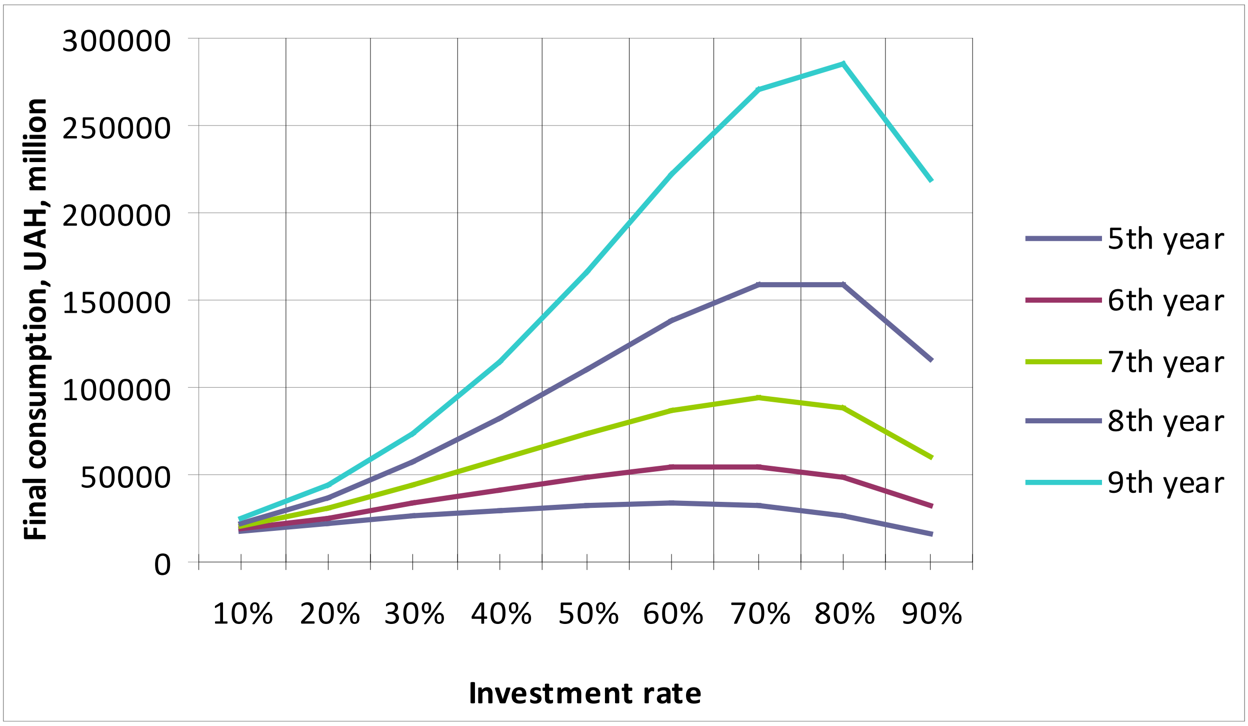


FIGURE 3. Final consumption for different years of planning period (5 – 9 years)



In addition, the selected planning period has an influence the value of r_s, which maximizes the final consumption. Thus, for a five-year planning period the share of investment in the final demand r_s = *50 %* is the best. However, the situation is changed if the planning period rises: for a six-year planning period the consumption is maximized for the share of investment r_s = *60 %*, for a seven-year and an eight-year planning period it is maximized for r_s = *70 %*.

4.2. The estimate of the trajectories of the economic development for different variants of investment in energy saving

Then we use the dynamic input-output model (5) - (9) for studying the influence of investing in energy-saving technologies on the Donetsk region's economy. The trajectories of the regional economic development will be calculated for different variants of investing in energy saving, and the results will be compared with the trajectories calculated for the base variant.

For these calculations it is necessary to construct so-called *investment functions* that reflect the dependence of input-output coefficients on investment in energy saving (see simplifying assumptions (3)). In consideration of the industrial specialization of the Donetsk region, these functions will be constructed for following main sectors of the regional industry: coal mining, metallurgy, electric-power, and machine building, based on information about energy-saving investment projects of enterprises in these sectors. It should be noted that the data about projects reflect different times, so we use different energy prices depending on the time of the projects' implementation for estimating changes in technological coefficients as a result of investing in energy-saving technologies. In addition, we accept the assumption that any project will be implemented one year after the beginning of the investment.

These investment functions should be non-linear according to the economic meaning of the input-output coefficients. As a result of processing of data about energy-saving projects, using the package *STATISTICA 6.0*, we obtained the statistically significant hyperbolic functions that characterize the impact of investments in reduce energy consumption for the four above-mentioned main industrial sectors of the Donetsk region.

Two of them are presented in Figures 3 and 4.

FIGURE 3. The dependence of changes in IO coefficient characterizing the costs of electricity on differences in investment in the coal mining industry

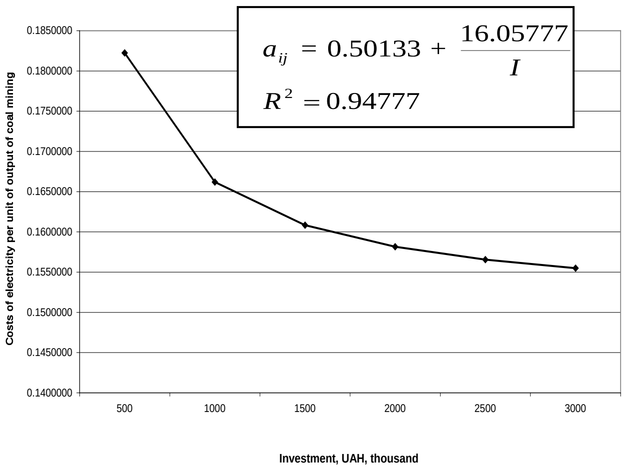
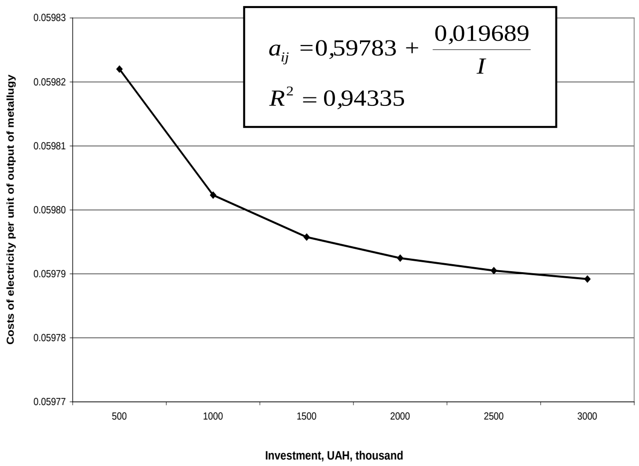


FIGURE 4. The dependence of changes in IO coefficient characterizing the costs of electricity on differences in investment in metallurgy



Giving the different values of the share of investments in the final demand r_s, we will calculate the trajectories of the economic development of Donetsk region for the following investment variants:

v=1 – investment has an effect on the structure of the current inputs, providing energy saving in coal mining;

v=2 – investment has an effect on the structure of the current inputs, providing energy saving in metallurgy;

v=3 – investment affects on the structure of the current inputs, providing energy saving in machine building;

v=4 – investment has an effect on the structure of the current inputs, providing energy saving in electric-power.

We achieved these calculations using *MathCAD* 13. Calculated values of the average final consumption for a five-year planning period, taking into account the basic variant ($v = 0$), are shown in Table 1.

TABLE 1. The average final consumption for the planning period $T_k = 5$, UAH, million

Investment rate	*Investment variants*				
	v = 0	*v = 1*	***v = 2***	*v = 3*	*v = 4*
10 %	14 190, 5	14 193,4	14 710,3	14 190,5	14 199,3
20 %	15 375, 4	15 378,9	15 989,8	15 375,4	15 385,9
30 %	16 349,1	16 353,1	17 056,9	16 349,1	16 361,2
40%	16 962,0	16 967,5	17 752,8	16 962,0	16 975,5
50 %	17 030,5	17 035,3	**17 881,1**	17 030,5	17 045,0
60 %	16 333, 6	16 338,5	17 203,8	16 333,7	16 348, 5
70 %	14 610, 3	14 614,9	15 437,4	14 610,3	14 624,5
80 %	11 555, 9	11 560,0	12 248,6	11 556,0	11 567,8
90 %	6 819,1	6 821,8	7 250,8	6 819,4	6 826,8

Based on Table 1, the maximum of the optimization criterion of the economic development of the Donetsk region *E* = 17,881,1 (UAH, million)* is achieved when the share of investment in the final demand is r_s = *50 %*, and the economic development is accomplished in accordance with investment variant *v=2*.

4.3. The estimate of optimal trajectories of the economic development for different planning periods

Optimal estimates change if the planning period is increased from five years to ten years. The results of the model calculations can be seen in Table 2.

TABLE 2. The average final consumption for the planning period *T* = 10, UAH, million

Investment rate	*Investment variants*				
	v = 0	*v* = 1	***v* = 2**	*v* = 3	*v* = 4
10 %	18 522,3	18 526,1	19 200,7	18 522,3	18 533,7
20 %	26 817,2	26 823,2	27 888,8	26 817,3	26 835,5
30 %	38 526,1	38 535,5	40 193,9	38 526,2	38 554,6
40 %	54 093,9	54 108,1	56 615,7	54 094,0	54 137,0
50 %	73 177,8	73 198,4	76 8323,0	73 178,0	73 240,4
60 %	93 802,1	93 830,3	98 800,0	93 802,3	93 887,7
70 %	111 027,9	111 063,4	117 312,9	111 028,2	111 135,6
80 %	114 956,7	114 995,6	**121 846,7**	114 957,0	115 074,7
90 %	87 837,4	87 868,8	93 394,4	87 837,6	87 932,6

An increase in the planning period to T_2 = *10 years* leads to an increase in the share of investment r_s^*, which obtains optimization the trajectory of the economic development of the Donetsk region for the same investment variant. If the planning period is increased to T_3 = *15 years*, it does not have an influence on the optimal values r_s^* and v^*, and only the optimal value of the final consumption is increased.

CONCLUSIONS

The sustainable balanced economic development of the Ukrainian industrial regions requires appropriate structural changes by the reduction of energy intensity in industrial sectors. We considered the estimate of the influence of investing in energy-saving technologies of these industries based on the discrete dynamic input-output model. The modeling calculations were implemented for the Donetsk region as one of the largest Ukrainian industrial regions.

The investment functions were introduced in this model for a quantitative substantiation of influence of investment in energy saving to changes in input-output coefficients that characterize the different energy costs per unit of sectoral output. We constructed these functions for the main industrial sectors of the Donetsk region: coal mining, metallurgy, machine building, and electric power. The important features of these functions are both reducing to a comparable type of information from investment projects done at various time and taking into account the time lag between investments and returns from them.

The trajectories of the balanced proportionate economic development of the Donetsk region were estimated using the dynamic input-output model. The calculations of these trajectories were based on both the variant investing in energy-saving technologies, and the share of investment allocated in the final demand. The choice of the best trajectory of economic development of this region was substantiated by the criterion of maximizing the annually averaged final consumption for a given planning period. The estimates of the optimal trajectories of economic development of the Donetsk region in the planning periods to five, ten, and fifteen years showed that in all cases the maximization of the optimality criterion was achieved by investment variant, which provided savings on electricity and gas in metallurgy. At the same time, the share of investments in the final demand, which meets the optimum, increases as the planning period is lengthened.

The model considered here is a useful tool for substantiating state programs for economic development of industrial regions. In particular, it has been applied to develop the Economic and Social Development Program of the Donetsk Region in 2007-2011, the Concept of Innovation Development of the Donetsk Region until 2020, and the Program of Medium-Term Priority Areas of Innovation in the Donetsk Region in 2012.

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