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FACTOR ANALYSIS OF THE CO2 EMISSIONS IN THE UNITED STATES WITH IMPLICATIONS FOR THE ENVIRONMENTAL POLICY

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ABSTRACT

This paper applies the Generalized Divisia Index to decompose the CO2 emissions into eight components and uses the Factor Analysis to determine their clusters - the combinations of related components that play the leading role. Economic analysis of these clusters allows for the determination of the main drivers of the CO2 emissions. As a case study, we used the data of the United States from 1950 through 2040 separated into three periods: 1950 - 1980; 1981 - 2012, and 2013 - 2040, each characterized by a specific type of socioeconomic development: industrial, post-industrial, and information, respectively. Data for the last period are projections. As a result, we got an insight into the typology of the CO2 emissions and obtained recommendations on environmental policy aimed at their mitigation

Indexing terms/Keywords

CO2 emissions, Environmental policy, Generalized Divisia Index, Kaya identity, Factor analysis, Cluster analysis, Typology.

Academic Discipline And Sub-Disciplines

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INTRODUCTION

As the report of the Intergovernmental Panel on Climate Change, ICCP (2014), states, human intervention aimed to reduce the sources of greenhouse gases (GHG) is strongly needed to prevent global warming and climate change. As this report also mentions, the opportunities for the mitigation of the CO2 emissions are limited due to the existence of economic, societal, and cultural differences among countries. The GHG mitigation policy should be consistent with sustainable development, equity, value judgements and ethical considerations. Also, all individual agents should be prepared to forego some of their own interests. Finally, the climate policy is subject to the ability of individuals, organizations, and countries to perceive related risks and uncertainties.

Fossil fuel combustion and industrial processes contribute about 78% of the total. Between 2000 and 2010, the increase in anthropogenic GHG emissions resulted from energy supply (47%), industry (30%), transport (11%) and buildings (3%) sectors. Among the most important drivers of the increase in GHG emissions were economic development and population growth. Without the relevant mitigation policies, this trend may begin threatening the human wellbeing and even existence.

The instruments available for the policymakers are different in the societies located at different stages of economic development because the differences in the main sources of economic growth. In this paper, we distinguish among the three main types of the societies: industrial, post-industrial, and information. In the industrial society, the most of the gross domestic product is generated in the industrial sectors of the economy. When collection of the service sectors takes the lead, the society is referred to as post-industrial, Bell (1973). Finally, when creation, use, and manipulation of information becomes the main factor of international competitive advantage, the society reaches the information stage, Beniger (1986). This paper covers the period of 1950 through 2040 during whichn the United States passed the first two stages and is expected to enter the third, the highest, stage of the information society. We demonstrate how the CO2 factor structure changes depending on the level of economic development. The investigation of this change is important in view of the practical significance of the mitigation of the CO2 emissions. The main objective is to help determine the driving forces behind the CO2 emissions and suggest the ways of change in the environmental policies that are relevant to the level of economic growth.

The tools of investigation used in this paper are the Generalized Divisia Index Method (GDIM), Vaninsky (2014), and Factor Analysis, Thompson (2004). The paper is organized as follows. Section 2 presents the mathematical model, Section 3 the results and their discussion, and Section 4 provides conclusive remarks and outlines possible next steps.

MATHEMATICAL MODEL

In this section, we follow Vaninsky (2014) in the description of the mathematical means used in this paper. The basic tool is the factorial decomposition of the CO2 emissions of factors as suggested by Kaya identity, Kaya (1990), extended to include the interconnected factors, Vaninsky (1983, 2014). Methodologically, the Kaya identity may be traced to the seminal publications of Laspeyres (1871), and Paasche (1874). These publications suggested the additive decomposition of the resultant indicator Z given in the multiplicative form

$$Z = X_1 \cdot X2 \cdot \ldots \cdot X_n, \tag{1}$$

as

$$\Delta Z = \Delta Z[X1] + \Delta Z[X2] + \ldots + \Delta Z[Xn], \tag{2}$$

where ΔZ and $\Delta Z[Xi]$ stand for the change in Z and its parts corresponding to the factorial indicators X_i, respectively. The idea was to change the factorial indicators Xi one at a time and to assign at each step the partial change in the level of Z to a factor X_i, respectively. One of the disadvantages of this approach is the necessity of a priori ordering of the indicators X_i. This weakness was overcome in the publication of Divisia (1925) that suggested the statement of the problem in continuous time. This publication assumed that the factorial indicators change continuously in time as $X_i = X_i(t)$, so that the necessity to put the factorial indicators in order was eliminated. The continuous-time factorial decomposition is as follows :

$$\Delta Z = \Sigma\, \Delta Z[X_i] = \Sigma \int X_1 \cdot X_2 \cdot \ldots \cdot X_{i-1} \cdot X_i' X_{i+1} \ldots \cdot X_n \cdot dt, \tag{3}$$

where Σ is the summation symbol, symbol $\int$ stands for the integration, X_i' is the derivative of X_i by time t, and integration is done by time t as well. With this approach, the impact of a factor X_i on the change in the resultant indicator Z is as follows:

$$\Delta Z[X_i] = \int X_1 \cdot X_2 \cdot \ldots \cdot Xi\text{-}1 \cdot Xi' \cdot X_{i+1} \ldots \cdot X_n \cdot dt,\ i = 1..n. \tag{4}$$

This approach was further extended in Scheremet et al. (1971) to include any continuously differentiated functions, rather than products of the factorial indicators only. Assuming

$$Z = f(X) = f(X_1,\ldots,X_n), \tag{5}$$

the authors received the factorial decomposition as:

$$\Delta Z = Z_1 - Z_0 = \int_L dZ = \int_L f_1' dX_1 + \int_L f_2' dX_2 + \ldots + \int_L f_n' dX_n \tag{6}$$

where

$$\Delta Z[X_i] = \int_L f_i' dX_i = \int_{t_0}^{t_1} f_i' X_i' \, dt, \tag{7}$$

f_i' is a partial derivative with respect to the *i*-th argument, and $X_i' = dX/dt$. Formula (6) may be rewritten in the vector form as

$$\Delta \mathbf{Z} = \int_L \nabla Z^T \cdot d\mathbf{X} \tag{8}$$

where $\Delta\mathbf{Z}$ is a row decomposition-vector with components $\Delta Z[X_i]$,

$$\nabla \mathbf{Z} = < f_1', \ldots, f_n' >^{\mathrm{T}} \tag{9}$$

is a column gradient vector of the function $f(X_1, \ldots, X_n)$, upper index T stands for the transposition, the dot-symbol stands for the dot-product of two vectors, and $d\mathbf{X}$ is a diagonal matrix with elements $dX_1, dX_2, \ldots, dX_n$.

Publications of Meerovoch (1974) and Vaninsky and Meerovich (1978) introduced a new class of the decomposition problems related to the structural change; see Maital and Vaninsky (2000) for details. The division - Sheremet approach was extended further in publications Vaninsky (1983, 1986) by the introduction of the factorial indicators that are not included in the model directly. This approach was applied in Vaninsky (2014) to the decomposition of the CO2 emissions. We will refer to it in this paper below as a Generalized Divisia Index Method (GDIM).

In the framework of the GDIM, the resultant indicator Z is a function of the factorial indicators $X_1, X_2, \ldots, X_n$ that are interconnected by a system of equations:

$$Z = f(X) = f(X_1, \ldots, Xn),$$

$$\Phi_j(X_1, \ldots X_n) = 0, \; j=1, \ldots, k \quad . \tag{10}$$

The second equation may be written in matrix form as

$$\boldsymbol{\Phi} \frown \boldsymbol{X} \overset{\smile}{\equiv} 0 \, . \tag{11}$$

The following formula was proved in Vaninsky (1984):

$$\Delta \boldsymbol{Z}[\boldsymbol{X} \,|\, \boldsymbol{\Phi}] = \int_L \nabla \boldsymbol{Z}^T (\, \boldsymbol{I} - \boldsymbol{\Phi}_x \boldsymbol{\Phi}_x^+) \; d\boldsymbol{X} \tag{12}$$

where coordinates of the row vector $\Delta \boldsymbol{Z}[\boldsymbol{X} / \boldsymbol{\Phi}]$ are the components of the factorial decomposition of the change in the resultiant indicator Z, and $\boldsymbol{\Phi}_X$ is a Jacobian matrix for the matrix-valued function $\boldsymbol{\Phi(X)}$:

$$(\boldsymbol{\Phi}_x)_{ij} = \frac{\partial \Phi_j}{\partial X_i}, \tag{13}$$

upper index "+" denotes the generalized inverse matrix, and $\boldsymbol{I}$ is the identity matrix. It is known that if the columns of the matrix $\boldsymbol{\Phi}_x$ are linearly independent, then

$$\boldsymbol{\Phi}_x^+ = (\boldsymbol{\Phi}_x^T \boldsymbol{\Phi}_x)^{-1} \boldsymbol{\Phi}_x^T. \tag{14}$$

See Albert (1972) for details. It should be mentioned that since the formula (12) uses an operator of projection on a surface, the factors should be measured in relative units; see Vaninsky (1984, 1987) for detail.

Vaninsky's publications (2013, 2014) applied this approach to decomposition of the CO2 emissions by factors of GDP, energy, population, their carbonization intensities, and other factors by extending the Kaya identity, Kaya (1990). This identity is a particular case of index model (1) adapted to environmental studies. It expresses the CO2 emissions as a product of carbon intensity of energy (*CO2/E*), the energy intensity of economic activity (*E/GDP*), GDP per capita (*GDP/P*), and population (*P*):

$$CO2 = (CO2/E) \times (E/GDP) \times (GDP/P) \times P \quad . \tag{15}$$

The impact of each of the factors can be computed by using either the discrete Laspeyres-Paasche approach or the continuous-time approach of Divisia. The Kaya identity is a useful practical tool for finding the ways of reducing the CO2 emissions. For example, the Kaya-identity-based decomposition is available as a part of statistical data published by the U.S. Energy Information Administration on its website www.eia.gov. This approach, however, may be critiqued from two viewpoints. Firstly, only the population indicator is included as a quantitative indicator; neither energy nor GDP is considered within the framework of the factorial model (15). Secondly, different factor models similar to (15) may be offered that lead to different factorial decompositions.

Keeping this in mind, we follow in this paper publication of Vaninsky (2014) and transform the Kaya identity into factor model (10), which allows for the expansion of the analytical base of Kaya identity by the inclusion of different quantities and relative indicators. To do that, we begin with an observation that CO2 emissions may be presented in one of the three ways:

$$CO2 = (CO2/GDP)\cdot GDP = (CO2/Energy)\cdot Energy = (CO2/Population)\cdot Population. \qquad (16)$$

Our objective is to incorporate all of them symmetrically into the factorial analysis. For the sake of readability, we use the following denominations: $Z = CO2$, X_1 = GDP, X_3=Energy consumption, X_5=Population; X_2, X_4, and X_6 are the carbon intensities: X_2 = (CO2/GDP), X_4 = (CO2/Energy), X_6=(CO2/Population), correspondingly. Following Vaninsky(2014), we included two more relative indicators in the model to increase its explanatory power: X_7=(GDP/Population), and X_8 = (Energy/GDP).

In terms of the newly defined variables, formula (16) becomes

$$Z = X_1X_2 = X_3X_4 = X_5X_6. \qquad (17)$$

To apply the GDIM, we separate these equations into a factor model and equations of the factors' interconnections as follows:

$$Z = X_1X_2,$$

$$X_1X_2 = X_3X_4, \quad X_1X_2 = X_5X_6, X_7 = X_1/X_5, X_8 = X_3/X_1. \qquad (18)$$

and rewrite the equations (18) in the form (10):

$$Z = X_1X_2,$$

$$X_1X_2 - X_3X_4 = 0,$$

$$X_1X_2 - X_5X_6 = 0,$$

$$X_1 - X_5X_7 = 0,$$

$$X_3 - X_1X_8 = 0. \qquad (19)$$

As shown in Vaninsky (2014), a gradient of the function $Z(X)$ and the Jacobian matrix $\boldsymbol{\Phi}_x$ are as follows:

$$\nabla \boldsymbol{Z} = < X_2, X_1, 0,0,0,0,0,0 >^{\mathrm{T}},$$

$$\boldsymbol{\Phi}_x = \begin{pmatrix} X_2 & X_1 & -X_4 & -X_3 & 0 & 0 & 0 & 0 \\ X_2 & X_1 & 0 & 0 & -X_6 & -X_5 & 0 & 0 \\ 1 & 0 & 0 & 0 & -X_7 & 0 & -X_5 & 0 \\ -X_8 & 0 & 1 & 0 & 0 & 0 & 0 & -X_1 \end{pmatrix}^{\mathrm{T}} \qquad (20)$$

In this paper below, the quantitative factors X_1=GDP, X_3=Energy consumption, and X_5=Population are considered exponential functions of a model time t, $0 \le t \le 1$. The range of the model time change does not affect the final result; see Vaninsky (1983, 1987) for details. By doing so, we get all of the remaining factorial indicators and the resultant indicator Z as the functions of the model time t as well in the form:

$$Q(t) = (Q_1/Q_0)^t, \qquad (21)$$

where Q stands for a quantitative or relative indicator X_i, or resultant indicator Z, and 0 and 1 are the lower indexes corresponding to base and final values, respectively. The derivatives with respect to time t are

$$\frac{dQ}{dt} = ln\left(\frac{Q_1}{Q_0}\right)Q\,. \qquad (22)$$

Publication Vaninsky (2014) presents a computer program in R-language, R Development Core Team (2011), that performs calculations. As a result, we obtain the decomposition of the chain rate of change in CO2 emissions into 8 factors mentioned above.

Our objective is to study the structure of the factorial decomposition obtained at different stages of economic development. To do so, we apply a technique of factor analysis, see Thompson(2004) for details. Factor analysis aims to represent a set of n variables as linear combinations of a smaller number of k factors. The factors are assumed to be independent random variables with zero mean value and a unit standard deviation. The terms of the linear combinations are called factor loadings. Factor analysis uses the rotation of the factors to make the factor loadings clearly separated by the variables. This allows for the interpretation of the variables having largest i-factor loadings as belonging to one cluster, related to this factor.

In matrix notation, the factor analysis model is as follows:

$$\boldsymbol{X} = \boldsymbol{\Lambda F} + \boldsymbol{U}, \qquad (23)$$

where $\boldsymbol{X}$ is an n^xN matrix representing N observations over n variables, $\boldsymbol{F}$ is a k^xN matrix of k factors, $\boldsymbol{\Lambda}$ is an n^xk matrix of factor loadings , and $\boldsymbol{U}$ is an n^xn uniqueness matrix. In this model, $k < n < N$, and a matrix product $\boldsymbol{\Lambda F}$ is interpreted as the communality of the variables. Factor analysis is aimed to make the matrix $\boldsymbol{U}$ as small as possible.

In this paper below, we use 8 factorial decomposition elements as variables that are observed during the time periods corresponding to different stages of economic development.

RESULTS AND DISCUSSION

In this section we use statistical data on the U.S. economy for the period of 1950 - 2040 available at the website of the U.S. Energy Information Administration www.eia.gov to obtain a deeper insight in the structure of the CO2 emissions. The data include indicators of CO2 equivalent emissions, GDP, energy consumption, and population. The data beyond 2013 are projections. The data were divided into three sets: 1950 - 1980, 1981 - 2012, and 2013 - 2040, roughly corresponding to the three different stages of the U.S. economy: industrial, post-industrial, and information. We expect that the environmental policy, technology and the use of energy are quite different in these periods, and we aim to detect and clarify these differences.

Quantitative data for 1950 - 2040 are given in table 1. Figures 1 and trends with the slope of 0.548 percentage points per year. There are just two sub-periods when the rates of the CO2 emissions decreased. Both relate to the recession periods of the 1980’s and 2008 - 2010. However, the dynamics of the rates of change in the CO2 emissions are quite different in these three periods. The average rates of increase in the CO2 emissions during the 1950 - 1980, 1981 - 2012, and 2013 - 2040 periods are 23.5, 4.0, and 2.3 mills, respectively. This means that the increase in the CO2 emissions in 1981 - 2012 is 5.9 times less, and in 2013 - 2040, is 1.7 times less with regard to the previous period. This observation is in line with our assumption that the type of economy - industrial, post-industrial, or information - is among the main factor of the CO2 emissions. The higher the level of the economy, the better technology is in use, the more attention is paid to the quality of life, and more possibilities become available to satisfy the advanced criteria of the CO2 mitigation.

We applied the Generalized Divisia Index method, Vaninsky (2014), to separate the rate of change in the CO2 emissions into 8 components. A program in R-language used for the computations is provided in that publication; the R language developed by the R Development Core Team (2011) is available for free download. The obtained results, separated by the periods of 1950-1980, 1981-2012, and 2013 - 2040, respectively, are shown in Table 2. Figure 3 presents average contributions of each component to the rate of change in the CO2 emissions. As follows from these data, the GDP remains the main factor of the increase in the CO2 emissions across the periods with decarbonization of GDP as the main factor of their decrease. The role of energy is essential in the first period only but its impact strongly decreases after that. Carbonization of the population is essential but reverses its effect from positive in the first period to negative in the two following ones.

To further investigate the structure of the CO2 rates of increase decomposition, we applied the technique of factor analysis, referring the reader to Thompson (2004) for details, implemented in R language version 3.3.1. We used the library PSYCH of the package MASS. We began with the determination of the number of factors by using the procedure VSS with rotation parameter *varimax*. For all three time periods, the number of factors varied from two to four depending on the criteria embedded in the procedure. For the factor analysis and finding the clusters among the decomposition variables, we applied the procedure ICLUST with up to four factors. The results are shown in table 3 and figure 4.

As follows from the obtained results, the first two clusters include, depending on the periods, the quantitative indicators of Energy consumption and GDP (industrial, 1950-1980), Energy consumption (post-industrial, 1981 - 2012), and GDP (information, 2013 -2040). This means that at the industrial stage, both GDP and energy are the CO2 drivers since the production processes are energy intensive. In the post-industrial stage, when a greater part of the GDP is produced by using low-energy technology, only the total amount of energy matters. As a result, the role of the GDP as a CO2 driver decreases and it moves to the less significant cluster 2. As the society moves to the information era, all sources of energy become less CO2- emitting, and, thus, only the scale of the economy becomes the primary quantitative factor. This leads to the increase in the rank of the GDP while the energy indicator moves to the cluster 3.

Observations over the relative indicators reveal that the carbonization of the population (the CO2 over population) keeps its important role in all three types of economies. It is in the cluster 1 in the industrial and information economies and in cluster 2 in the post-industrial economy. At the same time, there is a difference between the industrial and more advanced economies. In the industrial and information economies, a factor of economic development - GDP per capita - plays a role as a part of the cluster 2 while at the post-industrial stage it changes for the energy intensity of the GDP, the factor of industrial technology. It also may be mentioned that carbonization of the GDP factor is important at both advanced stages of economic development. It is a part of the cluster 1 in both post-industrial and information economies.

The mentioned changes in the clusters' compositions are suggested to play a role in the formulation of environmental policy aimed at mitigation of the CO2 emissions and finding the ways of its implementation via economic restructuring.

CONCLUSIONS

In this paper we analyzed the CO2 emissions for the periods of 1950-1980, 1980-2012, and 2013-2040, with data beyond 2013 being projections made by the U.S. Energy Information Administration. These periods roughly correspond to the

Table 1. Quantitative indicators [a]

Year	CO2[b]	GDP [b]	Energy [b]	Population [b]	Year	CO2[b]	GDP [b]	Energy [b]	Population [b]
(1)	(2)	(3)	(4)	(5)	(1)	(2)	(3)	(4)	(5)
1950	2529	2004	34616	152	1996	5510	9426	94022	269

1951	2671	2159	36974	155
1952	2611	2242	36748	158
1953	2670	2345	37664	160
1954	2553	2330	36639	163
1955	2819	2498	40208	166
1956	2910	2548	41754	169
1957	2882	2599	41787	172
1958	2827	2575	41645	175
1959	2934	2760	43466	178
1960	3038	2829	45086	181
1961	3064	2894	45738	184
1962	3187	3070	47826	187
1963	3309	3204	49644	189
1964	3442	3389	51815	192
1965	3587	3607	54015	194
1966	3782	3842	57014	197
1967	3875	3939	58905	199
1968	4098	4130	62415	201
1969	4270	4258	65614	203
1970	4395	4266	67838	205
1971	4446	4410	69283	208
1972	4673	4644	72688	210
1973	4876	4913	75684	212
1974	4718	4886	73962	214
1975	4578	4875	71965	216
1976	4866	5137	75975	218
1977	5018	5373	77961	220
1978	5087	5673	79950	223
1979	5166	5850	80859	225
1980	5002	5834	78067	227
1981	4646	5982	76106	230
1982	4405	5866	73099	232
1983	4377	6131	72971	234
1984	4614	6572	76632	236
1985	4600	6843	76392	238
1986	4608	7081	76647	240
1987	4766	7307	79055	242
1988	4984	7607	82709	245
1989	5070	7879	84786	247
1990	5039	8027	84485	250
1991	4993	8008	84438	253
1992	5087	8280	85783	257
1993	5189	8516	87424	260
1994	5262	8863	89091	263
1995	5323	9086	91029	266
1997	5584	9846	94602	273
1998	5636	10275	95018	276
1999	5688	10771	96652	279
2000	5868	11216	98815	282
2001	5761	11338	96168	285
2002	5804	11543	97645	288
2003	5855	11836	97978	290
2004	5975	12247	100162	293
2005	5999	12623	100282	296
2006	5920	12959	99630	298
2007	6024	13206	101296	301
2008	5841	13162	99275	304
2009	5424	12758	94559	307
2010	5623	13063	97722	309
2011	5498	13299	97301	312
2012	5361	13580	96065	315
2013	5421	13843	96494	317
2014	5426	14232	96644	320
2015	5418	14693	97729	322
2016	5382	15154	98473	324
2017	5418	15589	99341	327
2018	5452	15987	99975	329
2019	5469	16378	100428	332
2020	5476	16753	100731	335
2021	5487	17113	101126	337
2022	5498	17487	101483	340
2023	5506	17885	101860	342
2024	5519	18316	102167	345
2025	5526	18769	102453	347
2026	5527	19232	102638	349
2027	5531	19690	102858	352
2028	5531	20154	103047	354
2029	5528	20637	103141	357
2030	5527	21139	103267	359
2031	5524	21639	103373	361
2032	5524	22139	103497	364
2033	5530	22659	103706	366
2034	5538	23200	103996	368
2035	5546	23751	104284	370
2036	5554	24315	104603	372
2037	5564	24888	105023	374
2038	5580	25477	105518	377
2039	5591	26063	105934	379
2040	5599	26670	106312	381

Notes

[a] www.eia.gov

[b] CO2 - mln. metric tons from energy consumption, GDP-bln$2005, Energy-trillion btu, Population - mln. people

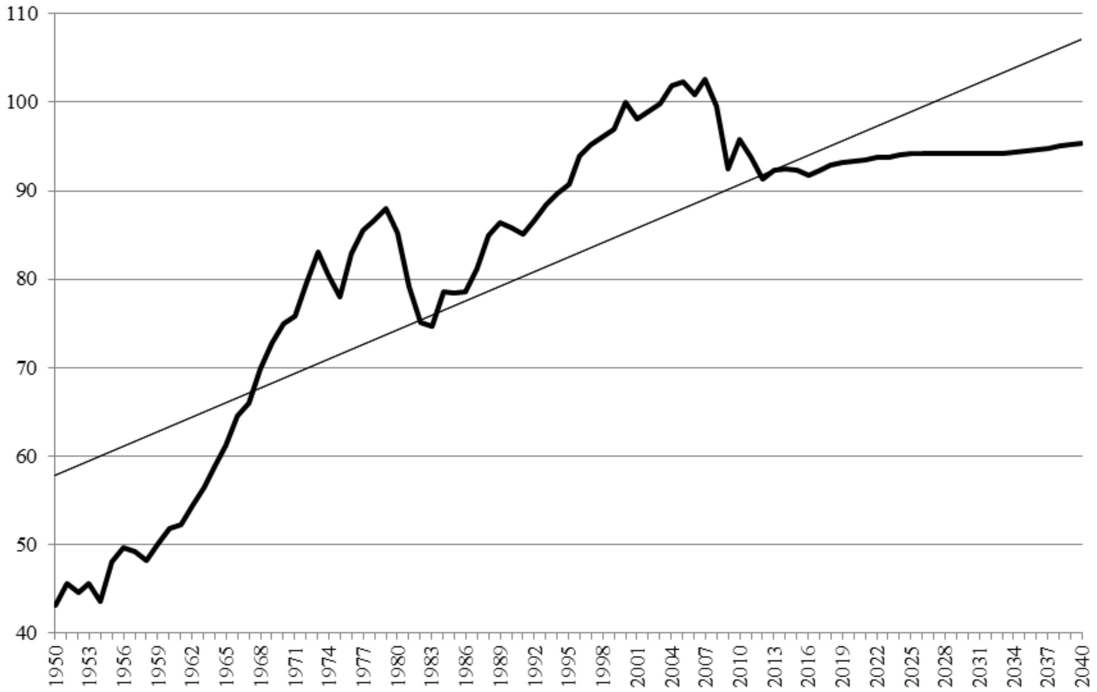


Fig. 1: CO2 rate, 2000=100%

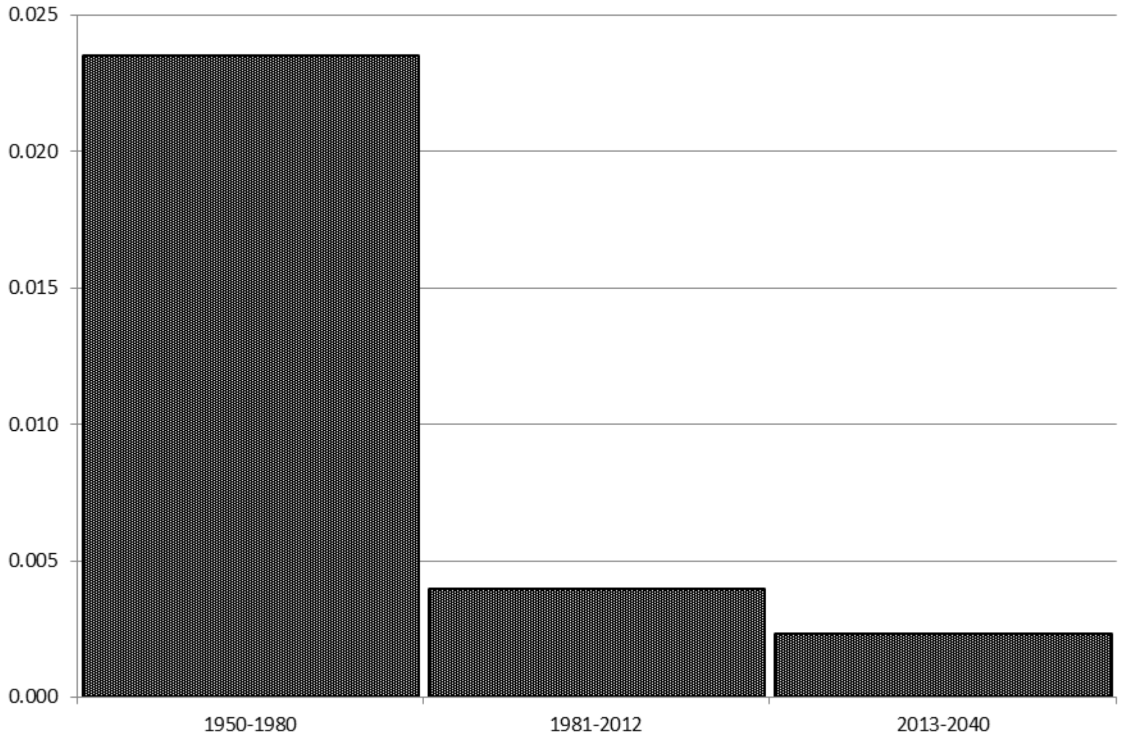


Fig. 2: Average rate of change in CO2 emissions

Table 2. Contributions to the rate of change in CO2

Year	GDP	Energy	Population	CO2/ GDP	CO2/ Energy	CO2/ Population	GDP/ Population	Energy/ GDP	CO2 chain rate, Total
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
1951	0.0259	-0.0067	0.0230	-0.0043	0.0057	0.0131	-0.0006	0.0000	0.0562
1952	0.0125	-0.0196	-0.0027	-0.0049	0.0057	-0.0132	0.0000	-0.0003	-0.0225
1953	0.0153	-0.0076	0.0090	-0.0015	0.0055	0.0020	-0.0001	0.0000	0.0226
1954	-0.0021	-0.0125	-0.0096	-0.0050	0.0057	-0.0201	-0.0001	-0.0001	-0.0438
1955	0.0245	0.0103	0.0332	0.0018	0.0061	0.0290	-0.0006	-0.0002	0.1042
1956	0.0066	0.0041	0.0133	-0.0024	0.0061	0.0047	0.0000	-0.0001	0.0323
1957	0.0066	-0.0098	0.0000	-0.0032	0.0060	-0.0092	0.0000	-0.0001	-0.0096
1958	-0.0030	-0.0034	-0.0016	-0.0048	0.0056	-0.0118	-0.0001	0.0000	-0.0191
1959	0.0239	-0.0107	0.0151	-0.0026	0.0055	0.0071	-0.0005	0.0000	0.0379
1960	0.0083	0.0035	0.0123	-0.0004	0.0055	0.0063	0.0000	0.0000	0.0355
1961	0.0077	-0.0048	0.0044	-0.0016	0.0055	-0.0027	0.0000	0.0000	0.0086
1962	0.0202	-0.0065	0.0153	-0.0019	0.0051	0.0083	-0.0003	0.0000	0.0401
1963	0.0146	-0.0018	0.0126	0.0002	0.0048	0.0079	-0.0001	0.0000	0.0383
1964	0.0193	-0.0057	0.0147	-0.0014	0.0048	0.0087	-0.0003	0.0000	0.0402
1965	0.0215	-0.0070	0.0141	-0.0001	0.0042	0.0099	-0.0004	0.0000	0.0421
1966	0.0219	-0.0035	0.0185	-0.0004	0.0040	0.0143	-0.0005	0.0000	0.0544
1967	0.0084	-0.0002	0.0111	-0.0029	0.0036	0.0046	0.0000	0.0000	0.0246
1968	0.0163	0.0030	0.0199	-0.0006	0.0034	0.0159	-0.0003	0.0000	0.0576
1969	0.0104	0.0036	0.0171	-0.0030	0.0034	0.0107	-0.0001	-0.0001	0.0420
1970	0.0006	0.0092	0.0112	-0.0014	0.0040	0.0058	0.0000	-0.0002	0.0293
1971	0.0111	-0.0072	0.0073	-0.0035	0.0042	-0.0004	-0.0001	0.0000	0.0116
1972	0.0179	-0.0007	0.0164	0.0006	0.0036	0.0136	-0.0003	0.0000	0.0511
1973	0.0194	-0.0046	0.0138	0.0007	0.0032	0.0114	-0.0004	0.0000	0.0434
1974	-0.0018	-0.0090	-0.0074	-0.0034	0.0031	-0.0138	0.0000	-0.0001	-0.0324
1975	-0.0007	-0.0092	-0.0089	-0.0009	0.0032	-0.0130	0.0000	-0.0001	-0.0297
1976	0.0181	0.0030	0.0186	0.0024	0.0031	0.0180	-0.0003	0.0000	0.0629
1977	0.0154	-0.0048	0.0088	0.0016	0.0034	0.0071	-0.0002	0.0000	0.0312
1978	0.0185	-0.0134	0.0085	-0.0039	0.0036	0.0010	-0.0003	-0.0001	0.0138
1979	0.0104	-0.0051	0.0037	0.0014	0.0037	0.0014	-0.0001	-0.0001	0.0155
1980	-0.0009	-0.0096	-0.0114	0.0010	0.0031	-0.0136	0.0000	-0.0002	-0.0317
Avrg	1.0366	1.0280	1.0134	0.9874	0.9956	1.0100	1.0228	0.9917	0.0235

Table 2. Contributions to the rate of change in CO2 (cont.)

Year	GDP	Energy	Population	CO2/ GDP	CO2/ Energy	CO2/ Population	GDP/ Population	Energy/ GDP	CO2 chain rate,Total
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
2013	0.0072	0.0024	0.0060	0.0036	0.0030	0.0066	0.0000	0.0000	0.0288
2014	0.0101	-0.0103	0.0006	-0.0002	0.0030	-0.0027	0.0000	-0.0001	0.0003
2015	0.0116	-0.0119	0.0043	-0.0049	0.0029	-0.0035	-0.0001	-0.0001	-0.0017
2016	0.0112	-0.0134	0.0029	-0.0055	0.0030	-0.0056	-0.0001	-0.0001	-0.0076
2017	0.0103	-0.0084	0.0034	-0.0008	0.0030	-0.0004	-0.0001	0.0000	0.0070
2018	0.0099	-0.0073	0.0025	0.0000	0.0030	-0.0005	0.0000	0.0000	0.0073
2019	0.0095	-0.0081	0.0018	-0.0006	0.0031	-0.0019	0.0000	-0.0001	0.0036
2020	0.0089	-0.0083	0.0012	-0.0007	0.0029	-0.0024	0.0000	-0.0001	0.0015
2021	0.0083	-0.0075	0.0015	-0.0007	0.0029	-0.0021	0.0000	0.0000	0.0023
2022	0.0085	-0.0076	0.0014	-0.0006	0.0029	-0.0021	0.0000	0.0000	0.0023
2023	0.0088	-0.0081	0.0014	-0.0009	0.0028	-0.0023	0.0000	0.0000	0.0017
2024	0.0093	-0.0083	0.0012	-0.0003	0.0028	-0.0019	0.0000	-0.0001	0.0028
2025	0.0096	-0.0090	0.0011	-0.0006	0.0028	-0.0023	0.0000	-0.0001	0.0015
2026	0.0095	-0.0093	0.0007	-0.0006	0.0027	-0.0026	0.0000	-0.0001	0.0002
2027	0.0092	-0.0088	0.0008	-0.0006	0.0028	-0.0025	0.0000	-0.0001	0.0008
2028	0.0091	-0.0090	0.0007	-0.0007	0.0026	-0.0027	0.0000	-0.0001	0.0000
2029	0.0093	-0.0094	0.0004	-0.0006	0.0026	-0.0028	0.0000	-0.0001	-0.0006
2030	0.0094	-0.0094	0.0005	-0.0005	0.0025	-0.0026	0.0000	-0.0001	-0.0002
2031	0.0091	-0.0092	0.0004	-0.0006	0.0025	-0.0027	0.0000	-0.0001	-0.0006
2032	0.0089	-0.0088	0.0005	-0.0005	0.0025	-0.0025	0.0000	-0.0001	0.0000
2033	0.0091	-0.0086	0.0008	-0.0004	0.0023	-0.0019	0.0000	-0.0001	0.0013
2034	0.0092	-0.0086	0.0011	-0.0005	0.0023	-0.0018	0.0000	-0.0001	0.0017
2035	0.0092	-0.0085	0.0011	-0.0005	0.0023	-0.0018	0.0000	-0.0001	0.0017
2036	0.0092	-0.0085	0.0012	-0.0006	0.0022	-0.0016	0.0000	-0.0001	0.0017
2037	0.0091	-0.0083	0.0016	-0.0009	0.0022	-0.0015	0.0000	-0.0001	0.0021
2038	0.0092	-0.0079	0.0018	-0.0007	0.0022	-0.0011	0.0000	0.0000	0.0034
2039	0.0089	-0.0080	0.0015	-0.0008	0.0021	-0.0013	0.0000	0.0000	0.0023
2040	0.0090	-0.0083	0.0014	-0.0008	0.0020	-0.0015	0.0000	-0.0001	0.0017
Avrg	0.0093	-0.0084	0.0016	-0.0008	0.0026	-0.0019	0.0000	-0.0001	0.0023

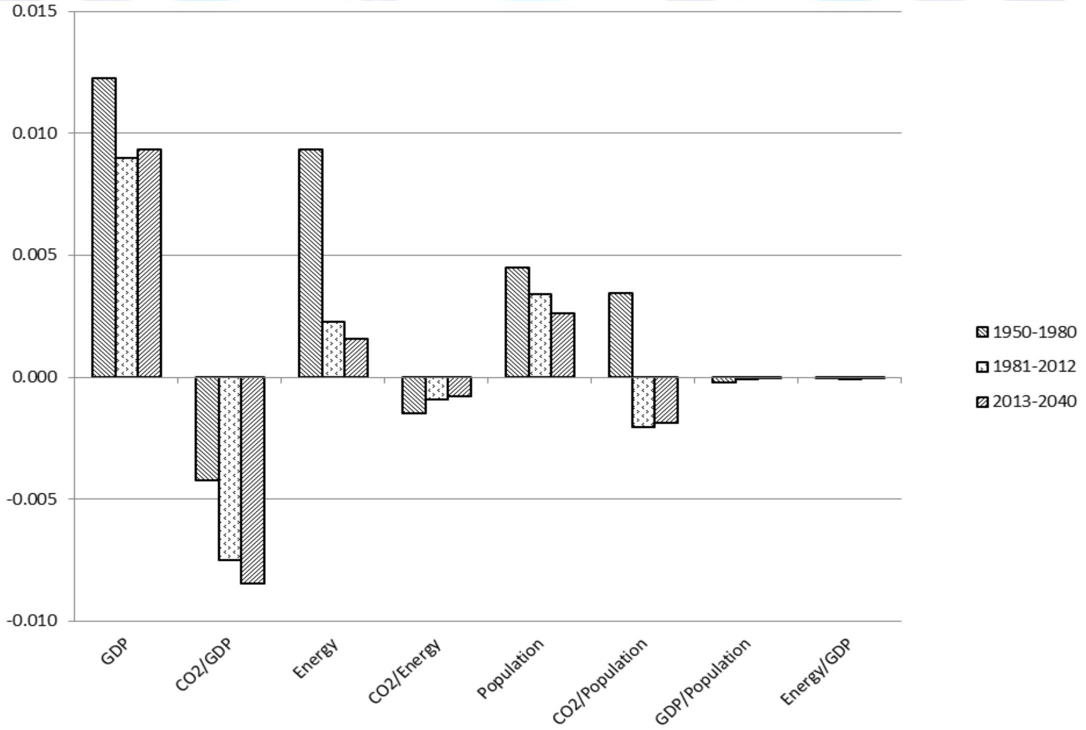
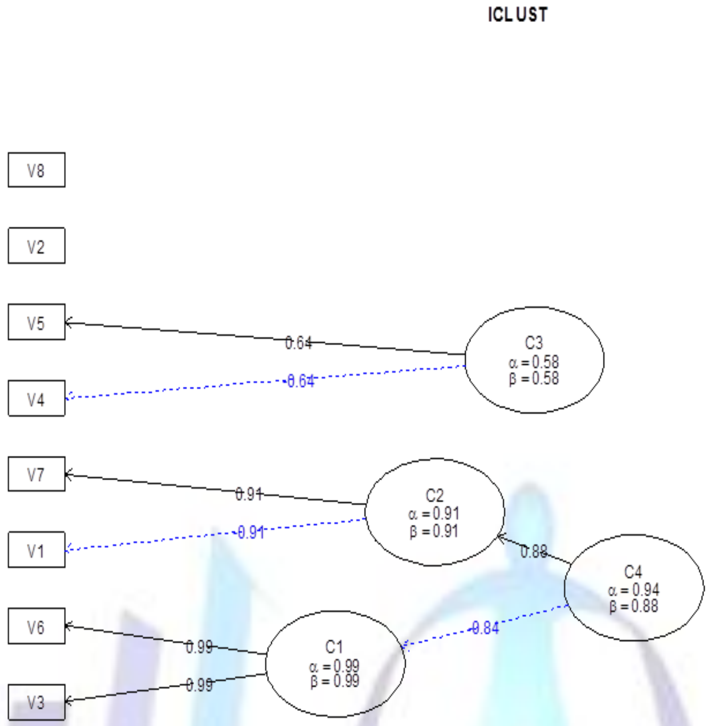
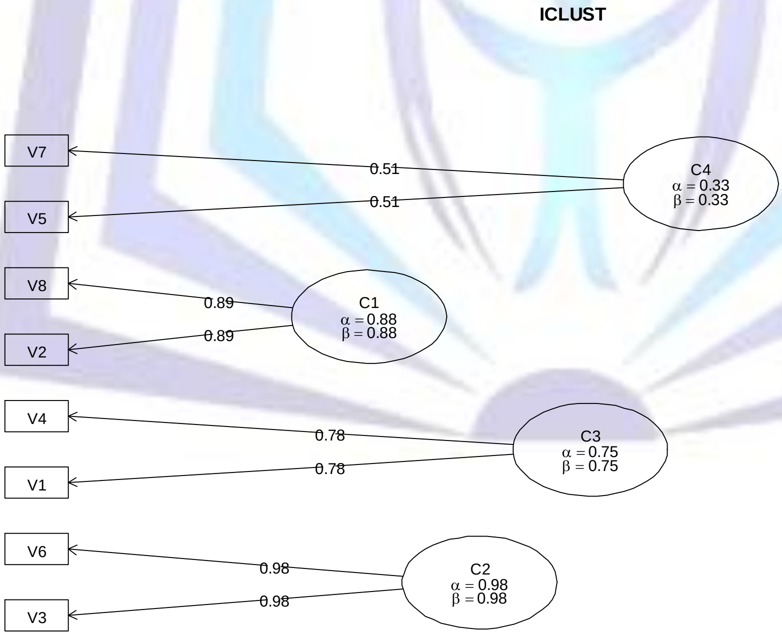


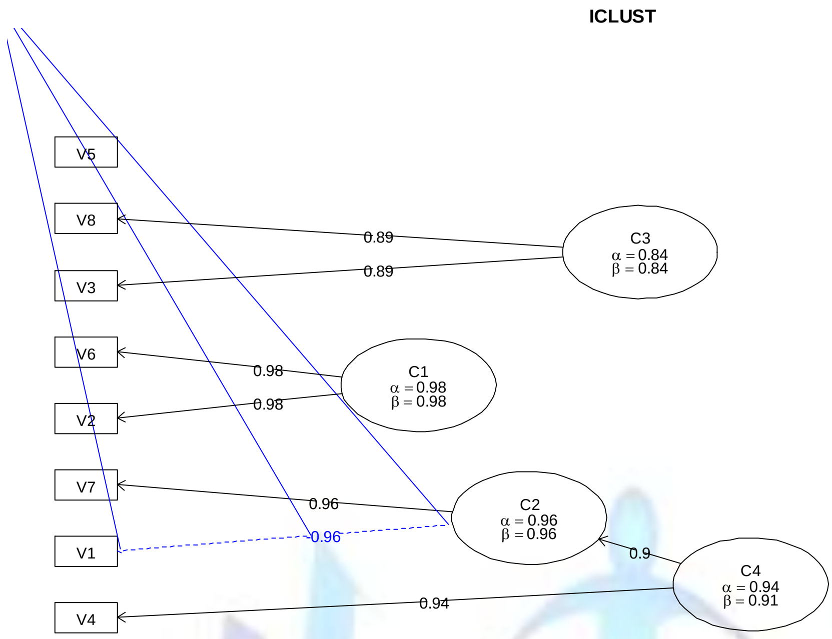
Fig 3: Average contributions to the rate of change in CO2 emissions



a) Clusters for the period of 1950-1980



b) Clusters for the period of 1981-2012



c) Clusters for the period of 2013-2040

Fig. 4: Clusters of the decomposition variables
V1 - GDP, V2 - Energy, V3 - Population, V4 - CO2/GDP, V5 - CO2/Energy, V6 - CO2/Population, V7 - GDP/Population, V8 - Energy/GDP.

Table 3. Clusters of variables by time periods, USA 1950-2040

	Variable	GDP	CO2/ GDP	Energy	CO2/ Energy	Population	CO2/ Population	GDP/ Population	Energy/ GDP
	Abbreviation	V1	V2	V3	V4	V5	V6	V7	V8
1951-1980	Cluster 1			X			X		
	Cluster 2	X						X	
	Cluster 3				X	X			
	Cluster 4								
1981-2012	Cluster 1		X						X
	Cluster 2			X			X		
	Cluster 3	X			X				
	Cluster 4					X		X	
2013-2040	Cluster 1		X				X		
	Cluster 2	X						X	
	Cluster 3			X					X
	Cluster 4				X				

industrial, post-industrial, and information types of the U.S. economy. The chained rates of the CO2 emissions were decomposed into 8 classes each corresponding to GDP, energy consumption, and population, their carbon intensities,GDP per capita, and energy intensity of the GDP. The components of the CO2 rates of change were further subjected to a factor analysis and then to cluster analysis to find the drivers of the CO2 emissions and the ways of their mitigation. We analyzed the dynamics of the clusters' structures corresponding to the main CO2 drivers as a function of the stage of socioeconomic development and determined the change in the roles of quantitative and qualitative indicators. These findings may be further developed to provide recommendations on optimal environmental policy and economic restructuring. The suggested approach may be used for the analysis of the economies of other countries from the CO2-emissions' mitigation perspective.

REFERENCES

[1] Albert, A. 1993. Regression and Moore - Penrose Pseudoinverse. 1972. Academic Press, New York,

[2] Bell, D. 1973. The Coming of Post-Industrial Society: A Venture in Social Forecasting, New York: Basic Books.

[3] Beniger, J. 1986.The Control Revolution: Technological and Economic Origins of the Information Society. Cambridge, Mass.: Harvard University Press.

[4] Divisia, F. 1925. L'indice Monetaire et la Theorie de la Monnaie, Revue d'Economic Politique, 39(5):980-1020. (In French).

[5] IPCC, 2014: Summary for Policymakers. In: Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Edenhofer, O., R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, A. Adler, I. Baum, S. Brunner, P. Eickemeier, B. Kriemann, J. Savolainen, S. Schlömer, C. von Stechow, T. Zwickel and J.C. Minx (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

[6] Kaya, Y. 1990. Impact of Carbon Dioxide Emission Control on GNP Growth: Interpretation of Proposed Scenarios. Paper presented to the IPCC Energy and Industry Subgroup, Response Strategies Working Group, Paris. (mimeo).

[7] Laspeyres, E. 1871. Die Berechnung einer mittleren Waarenpreissteigerung. Jahrbücher für Nationalökonomie und Statistik, 16, 296–315. (In German).

[8] Maital, S., Vaninsky, A. 2000. Productivity paradoxes and their resolution. Journal of Productivity Analysis, 14(3); 191- 207.

[9] Meerovich V. 1974. Turnover of Financial Funds and Efficiency of Production. (Oborot Sredstv Effektivnost' Proizvodstva), Financy, Moscow. (In Russian.)

[10] Paasche, H. 1874. Über die Preisentwicklung der letzten Jahre nach den Hamburger Börsennotirungen. Jahrbücher für Nationalökonomie und Statistik, 23:168–178.(In German).

[11] R Development Core Team. R: A language and environment for statistical computing. 2011. R Foundation for Statistical Computing,.Vienna, Austria. ISBN 3-900051-07-0, URL http://www.R-project.org/.

[12] Sheremet, A., Dei, G. Shapovalov, V. 1971. The method of the chain substitutions and development of the factorial analysis of the economic indicators (Metod tsepnykh podstanovok i sovershenstvovanie faktornogo analiza ekonomicheskikh pokazatelei). Vestnik Moskovskogo Universiteta, Ser. Ekonomika, 4:62-69. (In Russian).

[13] Thompson, B. 2004. Exploratory and confirmatory factor analysis: Understanding concepts and applications. American Psychological Association, Washington DC.

[14] Vaninsky, A. 1986. Analysis of production efficiency based on the generalized integral method (Analiz effectivnosti proizvodstva na osnove obobschennogo integral'nogo metoda) In Aksenenko, A. (Ed.) Accounting and analysis of production efficiency (Uchet i analiz effectivnosti proizvodstva). 6.1, 212-25. Financy i Statistika, Moscow. (In Russian).

[15] Vaninsky, A. 2013. Economic Factorial Analysis of CO2 Emissions: The Divisia Index with Interconnected Factors Approach. World Academy of Science, Engineering and Technology (WASET). International Journal of Management Science and Engineering, 7(10), 746-751. Available at http://waset.org/publications/17173/.

[16] Vaninsky, A. 2014. Factorial decomposition of CO2 emissions: A generalized Divisia index approach. Energy Economics, vol. 45, 389–400.

[17] Vaninsky, A. 1983. An extension of the integral method of economic analysis to the analysis of interrelated and derivative factors. Avtomatika i Telemekhanika, 8,130–141. Available at http://www.mathnet.ru/php/archive.phtml?wshow=paper&jrnid=at&paperid=5200&option_lang=eng (In Russian). English translation is available in Automation and Remote Control,1984, 44, 8(2), 1074 - 1083.

[18] Vaninsky, A., Meerovich, V. 1978. Problems of the methodology of analysis of the impact of structural change on the indicators of production efficiency, (Voprosy metodologii analiza vliyaniya strukturnykh sdvigov na pokazateli effectivnosti proizvodstva.) Proceedings of the National Scientific Conference "Economic Leverages of the Efficiency of Using Material, Labor, Finance, and Natural Resources", 2, 105 - 107, Central Economic -Mathematical Institute, Moskva. (In Russian).