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ANALYSIS OF ENERGY RESOURCES' FLOWS AS THE SUSTAINABLE DEVELOPMENT PARAMETERS

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Abstract. Global challenges require a transition from the existing linear economic model to models that will consider nature as a life support system for the development on the way to social well-being in the frame of the ecological economics paradigm. The article presents results of the development of formalizing the sustainable development monitoring using the concept of energy flows in open non-equilibrium stable socio-economic complex systems in the frame of ecological economics approach. The authors calculated and used a new system of universal parameters of sustainable development: total consumption of energy resources, total production, power losses and impact on environment, technological excellence. Level of human life was defined as a function of total production, environment changing, population changing and technological efficiency level. In context of considering approach, universal parameters were calculated using the data of Eurostat during the period from 1990 to 2019 and using statistical analyses methods. The main results: definition of the type and structure of the final consumption models (theoretical trends) on energy resources time series; allocation of stationary and non-stationary components in time series; calculation and primary interpretation of the system of basic parameters of a sustainable for the countries of Europe - Latvia, Lithuania, Estonia, Slovakia and Bulgaria. The countries as objects of research were selected in accordance with the following parameters: the population of each state is not more than 10 million and membership of the EU since 2004. The results of the research have indicated that there are several challenges in the analysed countries with several similarities, and there are possibilities to share and use the experience of energy resources flows approach for data analysis.

Keywords: sustainability, regional development, ecological economics, power, monitoring.

JEL code: E19, F69, Q59, R10

Introduction

Global challenges require a transition from the existing linear economic model to models that will consider nature as a life support system for the development on the way to social well-being in the frame of the ecological economics paradigm. According to the authors, the currently used methods for assessing the sustainability of the development of socio-economic systems do not allow presenting an objective picture of regional and national development. The countries of the European Union, in accordance with the concept of sustainable development, carry out a comprehensive accounting of many economic, social, environmental and other additional factors. This raises the problem of forming a scalar universal metric, in which both quantitative values of individual factors and generalized estimates of various levels, up to the global one, could be used. Monitoring the achievement of sustainable development goals, managing this process and evaluating effectiveness require the development of appropriate sustainable systems of criteria and indicators - indicators of sustainable development (Jermolajeva E. et al., 2021). Today's global economy has placed ecosystems and society at a critical juncture. When we look at the state of the world today, the most obvious fact is that the major problems of our time cannot be understood in isolation. These are systemic problems, which means that they are interconnected and interdependent. The application of measures at the level of symptoms is not satisfactory. Systemic solutions are needed to solve systemic problems. In this regard, the authors formulated three research questions.

First. The division of the sustainable development system into three separate systems (Economy, Ecology and Society) and their separate indication cannot give an idea and understanding of the

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performance results and development prospects of the entire socio-economic system as a whole. This is not consistent with a systematic approach.

Second. The main purpose of introducing indicators is to assess a situation or event in order to predict the development of the current situation and develop solutions to existing problems. To date, there is no single universal reasonable approach to determining the quantitative criteria to measure the degree of development sustainability. All indicators of sustainable development are obtained by different methods and are measured in different units of measurement. This approach is not sufficient for understanding the nature of processes, their management and monitoring.

Third. In today's changing world, in order to talk about the sustainable development of a socio-economic system, it is necessary to consider all processes in a stable coordinate system and measure in terms of a stable coordinate system. If this coordinate system is constantly subject to change, and this is exactly what happens in the money/processes coordinate system, then we will not be able to measure the effectiveness of sustainable development, design a monitoring system.

The aim of this article, in the context of the above provisions, is to propose a new approach to assessing the development of regional socio-economic systems in a stable coordinate system of energy flows, which makes it possible to give a more objective picture of identifying regions as sustainable socio-economic systems. The article presents definitions for developing a formalized description of sustainable development monitoring using the concept of total and net power in open non-equilibrium sustainable socio-economic systems.

The authors calculated and used a new system of universal parameters of sustainable development: total energy consumption, total production, electricity losses and environmental impact, technological excellence. In context of considering approach and using statistical analyses methods, universal parameters were calculated using the data of Eurostat covering the period 1990 - 2019. The main results presented in the article: definition of the type and structure of the final consumption models (theoretical trends) on energy resources time series; allocation of stationary and non-stationary components in time series; calculation and primary interpretation of the system of basic parameters of a sustainable development for five countries of Europe - Latvia, Lithuania, Estonia, Slovakia and Bulgaria. The countries as objects of research were selected in accordance with the following parameters: the population of each country is not more than 10 million and they are member states of the European Union since 2004.

Research results and discussion

1. Research methodology

Systematic and long-term sustainable solutions are needed, focused on how to build and develop sustainable communities, created in accordance with wildlife. Fritjof Capra (Capra F. et.al, 2017) call this a "systems view of life" because they are based on "systems thinking" as thinking in terms of relationships, patterns, and context. In our changing world, the economy must adapt to environmental constraints and principles, develop in accordance with the systemic principles of life in stable coordinate systems, using stable universal unified measurements. In accordance with the theory of complex systems (Thurner S., 2018), the base principles of life and functioning of socio-economic systems are defined as the following:

- complex systems are usually open systems for energy flows with a memory and exhibit behaviours that are emergent;
- complex systems may be nested, i.e. the economic system is "nested" in the society and the environmental systems and the environmental laws are "higher" than the economic laws;

- complex system is a dynamic network and contain feedback loops;
- relationships in complex system are non-linear, and a small perturbation may cause a large effect, a proportional effect, or even no effect at all.

In accordance with the complex system theory frame, with the concept of ecological economics and the methodology of the analysis of the energy flows in open, non-equilibrium stable systems, the socioeconomic model of sustainable regional development was considered. In order to formalize the tasks of sustainable development and based on the above formulated concepts (Trusina I. et al., 2021), the energy flows for the life open socioeconomic system (SES) are defined and presented in Fig.1. The main law of energy flow for an open life system is presented in formulae (1):

$$N(t) = P(t) + G(t) \quad (1)$$

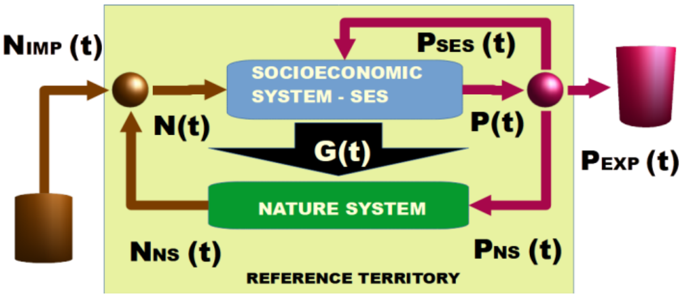
Where:

N(t) - full power or energy flow of socio-economic system;

P(t) - useful power or energy;

G(t) - part of the power G(t).

Figure 1 shows the full power (energy flow) N(t) of socio-economic system that received to the considered territory of the region as the sum of flows from the natural system N_{NS} (t) and external exports N_{IMP} (t). As a result of the activity, the SES loses part of the power G(t) and produces useful power (energy flow) P(t). Useful power P(t) is used to support the socio-economic system P_{SES}(t), to impact on the natural system to obtain the necessary resources P_{NS}(t) and to export P_{EXP}(t).



Source: author's construction

Fig. 1. **The power and flows of energy for life open socioeconomic system**

In accordance with the full power of SES definition (needs or final consumption, opportunities potential) N (t) is input power or total consumption of resources for a certain time, expressed in units of power watts (WT), calculated by formula (2):

$$N(t) = N1(t) + N2(t) + N3(t) \quad (2)$$

Where:

N(t) - the full power;

N1(t) - fuel consumption for machines, mechanisms and technological processes;

N2(t) - electricity consumption;

N3(t) - food consumption.

Useful power of SES (gross product produced or opportunities real) is the total product produced over time in units of watts (WT). Useful power is determined through the efficiency of the use of full power according to the formula (3):

$$P(t) = N1(t)^* J1 + N2(t)^* J2 + N3(t) * J3 \quad (3)$$

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Where: J was defined as follows: for fuel J1=0.25, for electricity J2=0.80, for food J3=0.05 (UNSC, 1974; Lindeman R., 1942).

Power losses of SES (opportunities lost) G(t) is the difference between the full power and the useful power of the system, expressed in units of watts (WT) calculated by formulae (4):

$$G(t) = N(t) - P(t) \quad (4)$$

In accordance with the power conservation law of living systems (Kuznetsov P., 2015), the main goal of SES development is to increase the amount of useful power P(t) and reduce losses G(t). Useful capacity depends on the level of technological development of the state. Basic framework of universal indicators for determination and monitoring of sustainable development for region are presented in Table 2 with nine basic indicators and six additional ones.

Table 2

Framework of universal indicators of sustainable development monitoring

N	Definition	Designation	Unit	Formulae
1	Full power consumption	N(t)	Watt	Formulae (2)
2	Useful power of system or GDP	P(t)	Watt	Formulae (3)
3	Losses of power or opportunities lost or impact on the environment	G(t)	Watt	Formulae (4)
4	Technological excellence	f(t)	x	f (t)= P(t) / N (t)
5	Quality of life	QoL (t)	Watt /people	$QoL(t)=U(t)*q(t)*T_A(t)$
6	Electricity part in full final consumption	EL(t)	x	EL(t) = N2(t)elec / N(t)
7	Power footprint	FOOT (t)	Watt/km2	F (t) = E(t) /S
8	Sustainability of the Quality of life	SQ (t)	x	SQ(t)= QoL(t) / D(t)
9	Labour productivity power	LP(t)	Watt/people	LP(t) = P(t) / ML(t)
	Additional:			
1	The standard of living	U(t)	Watt /people	U1(t) = P(t) / M(t)
2	Normalized time of active life	TA(t)	Year	$T_A(t)$= TAL (t) /100
3	Quality of environment	q(t)	x	q(t) = G(t) / G (t - 1)
4	Environmental impact factor	S (t)	x	S(t) = G(t) / N (t)
5	Environmental impact power	E(t)	Watt	E(t) = S(t) * P(t)
6	Full power per people	D(t)	Watt/people	D(t)= N(t) / M(t)

Source: author's construction based on Bolshakov B. et al., 2019

Positive and negative changes in the main indicators of energy flows (dN(t), dP(t), dG(t) and df(t)) of the natural socio-economic system determine the trend of its development at a certain interval (Table 3).

Table 3

The changes in the main indicators of energy flows (dN(t), dP(t), dG(t) and df(t)) and trends of socio-economic natural systems development

	State of the system	N(t)	P(t)	G(t)	f(t)
1	Growth "Zero"	dN = 0	dP = 0	dG= >0	df = 0
2	Growth extension	dN = 0	dP > 0	dG < 0	df = 0
4	Development	dN > 0	d P > d N > 0	dG < 0	df = > 0
5	Sustainable development	dN > 0	dP > 0	dG < 0	df> 0
8	Degradation	dN = 0	dP < 0	dG > 0	df =0
7	System collapse	N (t) > 0	P(t) = 0	G(t) =N(t)	df =0

Source: author's construction based on Bolshakov B. et al., 2019

Based on those parameters' changes combinations, it is possible to formulate the different trends in the socio-economic - natural systems' development according to the follow scenarios: growth "zero", growth extensive, growth intensive, development, sustainable development, degrowth, degradation and system collapse.

2. Information sources and data processing

The calculation of the indicators was carried out by using the data of EU Central Statistical Bureau for the period from 1990 to 2019 based on the sources indicated in the Table 4.

Table 4

Data definition and designation

Definition	Desig nation	Unit	Sources
Full final consumption	N (t)	Watt	Eurostat database
Final consumption of electricity	N(t)elec	Watt	Eurostat database Final consumption of electricity
Number of populations	M (t)	People	Eurostat database; Population
Labour people	ML (t)	People	Eurostat database
Gross Domestic Product	GDP (t)	Mln.Euro	Eurostat database; GDP
Life expectancy	TAL (t)	Years	Eurostat database
Area of references territory	S	Km2	Eurostat database

Source: author's construction based on EUROSTAT data

The calculation and primary interpretation of basic parameters' system of sustainability was carried out for Latvia, Lithuania, Estonia, Slovakia and Bulgaria. The main trends in the basic parameters (Table 5) - population, GDP and area of the territory in 1995 and 2019 are as follows: the significant population decline in Latvia, Lithuania, Estonia and Bulgaria; the slight population increase in Slovakia; a significant increase in GDP in all selected countries (Fig. 3). The increase was even, with a slight renewed decline in 2008-2009.

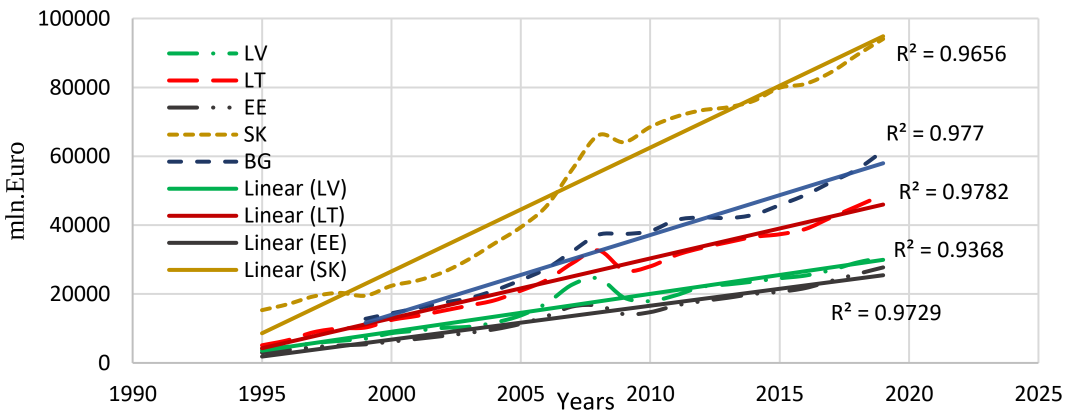
Table 5

Number of population M(t), area (S) and GDP of Latvia, Lithuania, Estonia, Slovakia and Bulgaria, 1995 and 2019

N	Countries	S, km2	M(t)			GDP(t)		
			1995	2019	changes	1995	2019	changes
			mln. people	mln. people	%	mln. Euro	mln. Euro	%
1	Slovakia	49 035	5.28	5.45	+3	15 323	94 048	+514
2	Bulgaria	110 994	8.76	7.00	-20	14 513	61 558	+324
3	Lithuania	65 000	3.69	2.79	-24	5 122	48 860	+854
4	Latvia	65 000	2.67	1.92	-28	4 137	30 647	+641
5	Estonia	45 000	1.57	1.32	-16	2 988	27 732	+828

Source: Author's calculation based on EUROSTAT data

The growth of the GDP for the period 1995-2019 is with linear tendency for all selected countries with rather high coefficients of determination with values from R^2=9368 till R^2 = 0.9782-as revealed in Figure 3 with all parameters of trends for the analysed countries with bigger change rate on the analysed aspect for Slovakia and lower growth rate for Estonia.



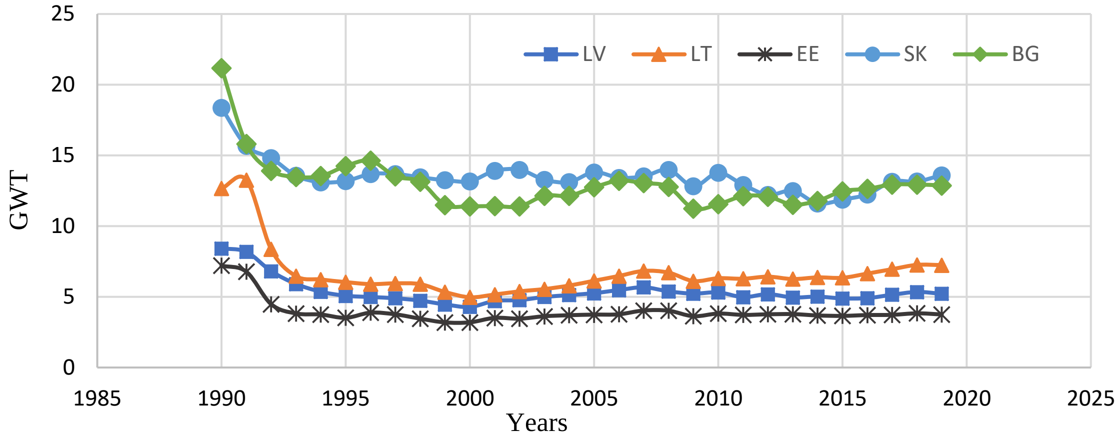
Source: Author's calculation based on EUROSTAT data

Fig. 3. **Changes of GDP with trend line in Latvia (LV), Lithuania (LT), Estonia (EE), Slovakia (SK) and Bulgaria (BG) for period 1995-2019, mln. euro**

Based on EUROSTAT data (Table 4), time dependencies were built for full consumption of resources (N(t)) (Power of SES, needs or potential opportunities) for Latvia, Lithuania, Estonia, Slovakia and Bulgaria for the period 1990-2019 (Fig. 4). For the selected countries, the main critical points and periods on the time axis were determined:

- 1990-1995- a period of significant post-soviet economic transformation and deindustrialization for all selected countries. This period is characterized primarily by a sharp decline in energy resources consumption in 2-3 times;
- 1996-2019 - after a sharp decline, all selected countries showed a constant level of consumption of energy resources.

The introduction of the term "power" into the formulation of sustainable development makes it possible to create an independent invariant system of coordinates and units of measurement. The new coordinate system in watts allowed us to rethink and analyse the development of selected countries in the period 1990-2019.



Source: Author's calculation based on EU Central Statistical Bureau data

Fig. 4. **Changes of full consumption of resources N(t) in Latvia (LV), Lithuania (LT), Estonia (EE), Slovakia (SK) and Bulgaria (BG), 1990-2019, GWatt**

Abnormal deviations were analysed and smoothed using the method of Irwin to detect abnormal levels time series (Jenkins G.M., 1994). The studied time series of consumption contains the main trend component and random noise (error). The method of negative exponentially weighted smoothing was also used. For all selected countries during the period 1995-2019, the main trend functions (Table 6) of energy consumption and electricity consumption (Table 7) were identified. In the equations for the consumption of total energy and electricity, x is a linear function of time t and is represented as a function of t(x) = x-1989, on the interval x ∈ [1990, 2019].

Table 6

Final energy consumption N(t) function for Latvia (LV), Lithuania (LT), Estonia (EE), Slovakia (SK) and Bulgaria (BG), 1995-2019

	Period, years		**Final consumption N1(t) function formulae**	**N(t) changes**
LV	1995	2019	N(t(x)) = const = 5.05 GWT	dN=0
LT	1995	2019	N(t(x)) = const = 6.19 GWT	dN=0
EE	1995	2019	N(t(t)) = const = 3.68 GWT	dN=0
SK	1995	2019	N(t(x)) = const = 13.17 GWT	dN=0
BG	1995	2019	N(t(x)) = const = 13.54 GWT	dN=0

Source: Author's calculation

The main trend of final consumption power of electricity was determined at different time intervals. As a consumption function, a polynomial of the second order and lower was used. The coefficient of determination R^2 was in the interval from 0.8080 till 0.9807. The point of change in the electricity consumption function for Estonia and Latvia is the crisis period of 2007-2008. The point of change for Lithuania is the year 2000 - the final completion of the transformation and a continuous slight increase in consumption, as well as for Bulgaria and Slovakia. The presence of a small share of nuclear power generation in these three countries reduced the impact of the 2008 crisis.

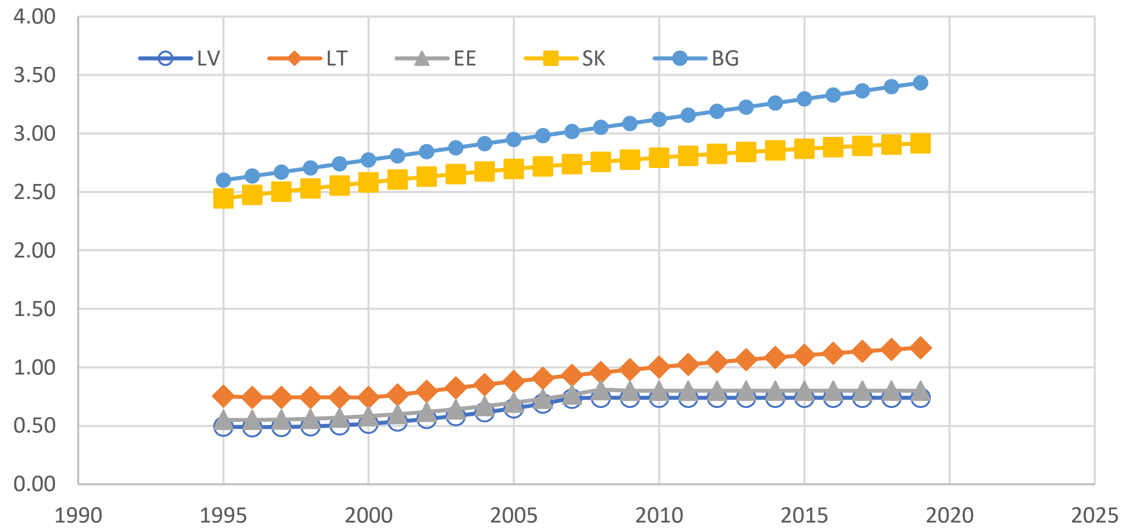
Table 7

Final consumption of electricity N2(t)(elec) function and main trend for Latvia (LV), Lithuania (LT), Estonia (EE), Slovakia (SK) and Bulgaria (BG), 1995-2019

	Period, years		**Final consumption electricity N2(t) (elec) function formulae**	**R^2**	**N2(t)elec changes**
LV	1997	2006	N2(t(x)) (elec) = $0.002x^2 - 0.031x + 0.602$	0.9807	dN>0
	2007	2019	N2(t(x)) (elec) = const = 0.74 GWT	0.9500	dN=0
LT	1995	2000	N2(t(x)) (elec) = const = 0.74 GWT	0.9500	dN =0
	2001	2019	N2(t(x)) (elec) = $0.006x + 0.683$	0.9732	dN >0
EE	1996	2006	N2(t(x)) (elec) = $0.002x^2 - 0.022x + 0.622$	0.9598	dN>0
	2007	2019	N2(t(x)) (elec) = const = 0.80 GWT	0.9500	dN=0
SK	1995	2019	N2(t(x)) (elec) = $0.03x + 2.26$	0.8080	dN>0
BG	1999	2019	N2(t(x)) (elec) = $0.03x + 2.39$	0.8924	dN>0

Source: Author's calculation

Based on the results of the calculations, graphs of trends in electricity consumption were constructed for Latvia (LV), Lithuania (LT), Estonia (EE), Slovakia (SK) and Bulgaria (BG) for period 1995-2019 (Fig. 5).



Source: Author's calculation based on EU Central Statistical Bureau data

Fig. 5. **Changes of main trend of electricity N2(t)(elec) in Slovakia (SK) and Bulgaria (BG),Latvia (LV), Lithuania (LT), Estonia (EE), 1995-2019, GWatt**

Using the formulas in Table 2 and the identified functions of the main trends in the total consumption of energy resources and electricity consumption, the main parameters of sustainable development were calculated for Latvia, Lithuania, Estonia, Slovakia and Bulgaria for period 1995-2019 (Tab. 8). According to the calculated data, the level of quality of life (QoL), as an integrated power per person, for all selected countries is close in value and is less than 1 kilowatt. Estonia, Slovakia and Bulgaria have a higher technological level (f) and a higher sustainable quality of life (SQ). The production of useful power by one person (LP) is on average the same for the selected countries and is 3-4 kilowatts per person and its correlation coefficient with the quality of life (QoL) is 0.8017.

Table 8

Sustainable development parameters of Latvia, Lithuania, Estonia, Slovakia and Bulgaria, 2019

No	Countries	trend of growth	f	EL	QoL	SQ	FOOT	LP
			x	%	kWT/people	x	kWT/km^2	kWT/people
1	Estonia	zero	0.40	22	0.8	0.28	20	4.0
2	Bulgaria	extension	0.37	25	0.6	0.28	30	3.0
3	Slovakia	extension	0.35	22	0.7	0.28	65	3.0
4	Lithuania	extension	0.32	19	0.6	0.26	23	3.0
5	Latvia	zero	0.30	15	0.7	0.23	18	3.0

Source: Author's calculation

In accordance with the parameters of Table 3 and the calculated changes in the main indicators of the natural socio-economic systems of five countries, their level of development was determined at certain intervals. Slovakia and Bulgaria, with constant consumption over the entire period 1995-2019, show extensive development.

Table 9

Sustainable development growth parameters and trends of Latvia, Lithuania, Estonia, Slovakia and Bulgaria, 1995-2019

	Formulae	dN	dP	dG	df	dM	Trend
Latvia							
1995 -2007	P (t(x)) = 0.01x - 17.72 G (t(x)) = -0.01x +30.83	=0	>0	<0	>0	<0	growth extension
2008-2019	P (t) = 1.68 GWT =const G (t) = 3.68 GWT =const	=0	=0	=0	=0	<0	growth zero
Lithuania							
1995 -2000	P (t) = 1.98 GWT = const G (t) = 4.72 GWT = const	=0	=0	=0	=0	<0	growth zero
2001-2019	P (t(x)) = 0.01x - 22.44 G (t(x)) = -0.02x + 39.27	=0	> 0	< 0	> 0	<0	growth extension
Estonia							
1995 -2009	P (t(x)) = 0.01x - 16.62 G (t(x)) = -0.01x + 23.49	=0	>0	<0	>0	<0	growth extension
2010 -2019	P (t) = 1.37 GWT = const G (t) = 2.51 GWT = const	=0	=0	=0	=0	<0	growth zero
Bulgaria							
1995 -2019	P (t(x)) = 0.02x - 32.30 G (t(x)) = -0.03x + 65.15	=0	>0	<0	>0	<0	growth extension
Slovakia							
1995 -2019	P (t(x)) = 0.01x - 16.87 G (t(x)) = -0.01x + 29.64	=0	>0	<0	>0	>0	growth extension

Source: Author's calculation

Such a long period of zero growth can bring the system to an equilibrium, which could negatively affect the further development of the socio-economic system and even lead to degradation.

Conclusions, proposals, recommendations

1) Deeper analysis and further construction of natural socio-economic systems within the framework of complex systems' theory makes it possible to appropriately develop and practice models for their study as complex nested nonlinear systems with memory and feedback. The introduction of the term "power" in the formulation of sustainable development allows to create a stable system of coordinates and units of measurement (watts), which allows us to create a measurable relationship between the needs and opportunities, as well as a system of indicators and criteria for sustainable development.
2) Sustainable development is a continuous process of building opportunities to meet the current needs of the existing socio-economic system in units of power now and in the future, improve the efficiency of using the full power of the system, reduce power losses and increase consumption in the face of negative external influences and internal influences.
3) The new coordinate system in watts allowed us to reimagine and analyse the development of selected countries in the period 1990-2019. For the selected countries, the main critical points and periods on the time axis were determined: 1990-1995 a period of significant economic transformation and deindustrialization for all selected countries; 1996-2019 - after a sharp decline, all selected countries showed a constant level of consumption of energy resources.
4) Within the framework of the energy flow analysis approach and the proposed stable coordinate system in watts, a basic system of indicators for monitoring the sustainable development of natural socio-economic systems was developed. Base indicators were calculated and primary ones interpreted for five European countries - Latvia, Lithuania, Estonia, Slovakia, Bulgaria.
5) According to the results of the analysis of the basic indicators, the data of Slovakia and Bulgaria showed continuous extensive growth throughout the entire period of the study. In Latvia and Estonia, after the crisis of 2008, zero development was established.

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