THE MAIN INDICATORS OF THE ECONOMY DIGITAL TRANSFORMATION IN THE CONTEXT OF NEW APPROACH TO SUSTAINABILITY

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Abstract

The paper focuses on key questions to the contemporary challenges call for a shift from the current linear economic model to models that will see nature as a life support system for social prosperity within the ecological economy paradigm and digital transformation. The aim of the article is to present the model of open non-equilibrium socio-economic complex system and its sustainability conditions formalization in terms of an invariant coordinate system. As well as to present the results of a formalization of sustainable development monitoring using the energy flows changing analysis approach, and the impact of condition of digital transformation. The authors carried out an assessment of sustainable development and analyzed indicators of sustainable development and the level of digital and their correlation. When calculating the parameters, Eurostat data and UN databases were used. The authors presented the results and initial interpretation of the follow countries France, Sweden, USA, China, Russia. The paper reinterprets the significance of the digital transformation concept and further elaboration of the power approach for monitoring the socio-economic system development.

Keywords: sustainability, energy flows, power, techno-economical paradigm, digital transformation

Introduction

Humanity is now entering one of the most important periods in its history. The ideas and models of neoclassicism are being replaced by the updated approaches of Joseph Schumpeter, the provisions of ecological economics are being introduced into the concept of sustainable development more and more actively. The era of extensive growth and industrial development is coming to an end, and the modern

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economic system is in deep crisis. The ending Industrial Age was based on expanded reproduction and the involvement of all available resources in the economic turnover. But this stage in the development of the world economy is coming to an end. Until recently, industry required the creation of gigantic enterprises and social structures in order to take full advantage of economies of scale and standardization. Interchangeability became hallmarks of the second half of the 20th century. In this situation, the importance of the technologies level development increases. Possession of high technologies, especially leadership in them, means a strategic advantage in the modern world. The global COVID pandemic has led to an awareness and understanding of the importance for humanity to be prepared for impending challenges and develop sustainable development approaches in advance. In this regard, more and more clearly, contemporary challenges require a transition from the current linear economic model to models that will consider nature as a life support system for social prosperity within the framework of the green economy and digital transformation paradigm.

The methods currently used to assess the sustainability of the development of socio-economic systems do not provide an objective picture of regional and national development. Attempts by the EU countries to make an inventory of many economic, social, environmental and other additional factors in accordance with the concept of sustainable development are not successful. This determines the importance of the new approaches in developing a universal metric system, in which both quantitative values of individual factors and generalized estimates at different levels, up to the global one, can be used. Monitoring the achievement of sustainable development goals, managing this process and evaluating its effectiveness requires the development of appropriate systems of sustainable criteria and indicators. (Jermolajeva and Trusina, 2021). Today's global economy has put ecosystems and societies in a critical situation. The most obvious fact is that the greatest problems of our time, that are environment, using the resources and development of post-industrial digital society, cannot be understood in isolation. These are systemic problems, which means that they are interconnected and interdependent. Systemic solutions are needed to solve systemic problems.

In this regard, in this paper four topical research questions are formulated.

First. The division of the sustainable development system into three separate systems (Economics, Ecology and Society) and their separate reference cannot give an idea and understanding of the performance results and development perspectives of the whole socio-economic system. This is not in line with a *systematic approach*.

Second. In today's changing world, in order to talk about the sustainable development of a socio-economic system, all processes must be seen and measured in terms of an *invariant coordinate system*. If this coordinate system is constantly changed, and this is exactly what happens in the money/process coordinate system, then we will not be able to measure the effectiveness of sustainable development, to develop a monitoring system.

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

Fourth. Contemporary challenges call for a shift from the current linear economic model to models that will see nature as a life support system for social prosperity within the green economy paradigm and digital transformation. It is necessary to understand *what place the concepts of digital transformation* occupy in these processes.

The aim of the article is to present the model of open non-equilibrium socio-economic complex system and its sustainability condition formalization in terms of an invariant coordinate system. As well as to present the results of a formalization of sustainable development monitoring using the energy flows changing analysis approach, and impact of condition of digital transformation.

The countries were selected according to the following parameters: high level of GDP in the world and Europe (the USA, France, Sweden), high level of informatization (the USA, China, Sweden, France), growing economies (China, Russia).

The first part of the paper focuses on key questions concerning the concepts of techno-economical paradigm definition and digital economy. The second part considers the methodology of managing sustainable development by using the concept of energy flows or useful power changing in open, non-equilibrium socio-economic systems. The third part presents the main results and discussion.

1. Contemporary conditions for sustainable development

1.1. Development and techno-economical paradigm

According to the theory of technological revolutions and techno-economical waves (Perez, 2013), the world is constantly undergoing a successive change of technological revolutions that have certain periods and phases of development. At the same time, the periods of formation and deployment of the technological revolution are accompanied by a change in the old technical and economic paradigm of the previous technological revolution to a new one. Such a paradigm shift implies large-scale and fundamental economic, institutional and technological changes, including the transformation of the traditional methods of organizing and doing business (Perez, 2009). Techno economical paradigm (TEP) is group of technological aggregates that are distinguished in the technological structure of the economy, connected with each other by the same type of technological chains and forming reproducible integrity.

Each TEP is a holistic and sustainable formation, within which a full production cycle is carried out at the macro level, including the extraction and production of primary resources, all stages of their processing, and the production of final products that satisfy the corresponding type of public consumption. As a result of the transition to a new technological order, there is also a transition to new types of energy carriers, which lay the resource basis for the formation of the next TEP. The presentation of long-term technical and economic development as a process of changing technological patterns allows us to measure the processes of long-term economic development. The results of these studies revealed the formation and change of five technological modes, including the currently dominant technological mode of information and electronics (Table 1.). This approach made it possible to reveal the structure of a new technological order, the development of which will determine economic growth in the coming decades (Glazyev *et al.*, 2018). The change of technological patterns in the course of modern economic development is characterized by key technologies for converting energy into work, which is the core of the energy paradigm. It can be concluded that the transition to the next sixth technological mode occurs through the formation:

- of new technology platform;
- of new economy model;
- of new currency model;
- of new model for interrelationships between environment and society.

An important, or may be core, connecting element of all changes in the upcoming transition is information technology and digital transformation.

Table 1. Techno-economical paradigm time series and main core pattern

TEP	**start terms**	**Core of Technology pattern**	**Core of Energy pattern**	**Next core of Energy pattern**	**Core of Management pattern**
I	1771	Iron processing	Biomass		Mechanization
II	1829	Metallurgy	Steam engine	Coal	Concentration
III	1875	Steel production	Coal	Oil-Gas	Standardization
IV	1908	Automobile	Oil-Gas	Electricity	Production line
V	1971	Electronic	Electricity	Nuclear energy	ITC technologies
VI	2020-future	Nanotechnology	Nuclear energy	New energy sources	Digital economy

Source: Authors' construction based on literature review.

Along with the transition to a new technological paradigm, solving problems can be associated with the use of the technological factor in the concept of advanced development, within the framework of the ecological economy and digital transformation. The concept of advanced development is being built as a reindustrialization strategy and an institutional dynamics strategy. Advanced development is a concept that implies a high rate of economic growth in the medium and long term due to qualitative changes in institutions and the structure of the economy (Kolganov and Buzgalin, 2010). Technology is an important part of the advanced development concept. New technologies and the specialization of new knowledge underlie the implementation of the proactive strategy and make it possible. It is the ability to ensure advanced development based on permanent technological renewal that becomes the main contemporary driver in the development of both an individual economic entity, and a region and a state.

Today, the world is on the threshold of the sixth technological mode. Its contours are just beginning to take shape in the United States, Japan and China, and are characterized by a focus on the development and application of science-intensive „high technologies". Readiness for the transition to the next technological stage in the basic section of energy resources, according to the conclusion of the authors, can be determined by the following factors:

- the share of electricity use in final consumption and the rate of increase in this share.
- the main determining generators of electricity, primarily clean technologies and nuclear energy

1.2. Development and economy digital transformation

The digital transformation of the world's economy is the next stage of its global development, and a characteristic feature is the desire to overcome the limitations of economic expansion on the part of industrialized countries in the existing techno-economic paradigm. The process of digital transformation of the world economy as a new model of world economic relations, the material basis of which is new digital technologies, and information acquires the status of a key resource in social and economic processes. Politics, legal norms, traditions, culture, the level of economic development and education, as well as the technological basis play a significant role in the transformation of an economy or country. As a result of the digital transformation of the global economic architecture of the new digital economy scheme, which is characterized by exponential growth in data flows. Under these conditions, it is not the very fact of the existence of a resource that becomes important for economic entities, but the availability of data about this resource and the possibility of using it to plan their activities. The main definitions of digital transformation (see Table 2.) include the following basic concepts:

- a fundamental change in the structure of the economy;

- personalizing all the process of digitalization;
- the introduction of digital technologies in all aspects of human life;
- transformation of the culture and business processes of the companies.

Table 2. The economic digital transformation definitions development

Definition	**Information source**
Digital transformation is a manifestation of qualitative, revolutionary changes, which consist not only in individual digital transformations, but also in a fundamental change in the structure of the economy, in the transfer of value-added centers to the sphere of building digital resources and end-to-end digital processes.	World Bank Group[1]
Digital transformation is a continuous process of multimodal implementation of digital technologies that fundamentally change the processes of creating, planning, designing, deploying and operating public and private sector services, making them personalized, paperless, cashless, eliminating physical presence requirements, based on the consensus of the parties.	UN specialized agency for ICT ITU[2]
Digital transformation - significant changes in all sectors of the economy and society as a result of the introduction of digital technologies in all aspects of human life.	European Parliament[3]
Digital transformation is the process of using digital technologies to create new or change existing business processes, culture and customer experience in accordance with changing business and market requirements. This is a rethinking of business in the digital age - digital transformation.	SalesForce[4]
Digital transformation is the process of using digital technologies to transform existing traditional and non-digital business processes and services, or create new ones, in line with the changing market and customer expectations, thereby completely changing the way businesses are run and managed and how value is delivered to customers.	Whatfix[5]
Digital transformation is a broad business strategy applicable across all industries to solve traditional business challenges and create new	PTC[6]

[1] World Bank (2022), World Bank, Digital Development Overview: Development news, research, data, https://www.worldbank.org/en/topic/digitaldevelopment/overview.
[2] UN ICT (2021), UN specialized agency for ICT ITU, https://www.itu.int/hub/.
[3] European Parliament (2021), European Parliament, Retrieved: https://www.europarl. europa.eu /news/en/headlines/ priorities/digital-transformation.
[4] SalesForce (2022), https://www.salesforce.com/products/platform/what-is-digital - trans formation.
[5] Whatfix (2021), https://whatfix.com/digital-transformation/.
[6] PTC (2022), https://www.ptc.com/en/industry-insights/digital-transformation.

opportunities through the use of technology. This requires adopting entirely new ways of working and delivering value to customers.	
Digital transformation is not only an investment in new technologies, but also a deep transformation of products and services, organization structure, development strategies, customer relations and corporate culture. In other words, this is a revolutionary transformation of the organization model.	RBC[7]
Digital transformation transforms not only the technologies used, but also the culture and business processes of the company. This is a fundamental rethinking of the customer experience, business models and operations. It is a search for new ways to create value, generate revenue and improve efficiency.	SAP[8]

Source: Authors' representation based on literature review.

Currently, there is a rapid development of a new digital technological revolution, associated with fundamental changes in all socio-economic institutions, and sometimes even with the formation of new ones. The ongoing technological changes bring certain challenges in all areas. The main factors and key changes in the digital transformation of the economy (Shome and Shah, 2019), which significantly affect the conditions and the development of new conditions, include mobility, datafication, computerization, artificial intelligence, speed of process, ecosystem (see Table 3) (Kolganov and Buzgalin, 2010). A special place is occupied by another factor that causes specific economic effects for digital transformation processes - this is the network revolution, or networking.

Table 3. Key factors of the economy digital transformation

Key factor	**Factors description**
Mobility	Internet connectivity
Datafication	Growth in the amount of information
Computerization	Growth in computing power
Artificial intelligence	The processing of large amount of information
Speed	Acceleration of economic processes
Ecosystem	Complex innovation environment
Networking	Network technologies,

Source: Authors' representation based on Kolganov and Buzgalin, 2010.

McKinsey Global Institutes reports on the role and impact of information technology development on labor productivity have not shown a global and significant increase in productivity over the past 20 years. (MGI, 2018). After nine

[7] RBC (2021) retrieved https://www.jll.ca/en/case-studies/royal-bank-of-canadas-digital-transformation.

[8] SAP (2021) retrieved: https://www.sap.com/insights/what-is-digital-transformation.html.

years of recovery from the Great Recession, productivity growth remains close to historic lows in many advanced economies. Productivity growth is critical to raising wages and living standards, and helps increase consumer purchasing power and increase demand for goods and services. Thus, the slowdown in labor productivity growth reinforces fears about the impossibility of further economic growth. Growth in production was observed mainly in the service sector, in the financial sector and in industries that ensure the development of information technology. It can be said that information technology has not significantly affected food production and metal smelting. At a time when productivity is stagnating around the world, perhaps after all, artificial intelligence and automation can become a lifeline. These cutting-edge technologies promise lower costs, more efficient business processes and innovative new business models. But at the same time, the introduction of these technologies will change the usual pattern of work, requiring a completely different set of skills and abilities.

Undoubtedly, the digital transformation of the economy is important for development on a global scale, and at the moment a platform is being created for the transition to a new technological order. Advanced development based on digital transformation is an important factor in the future development of the global economy.

2.The new approach and research methodology of sustainability

2.1. Open complex system

Systematic and long-term sustainable solutions are needed to build and develop sustainable communities built in the world. Fritjof Capra (Capra *et al*., 2017) calls it a “systemic view of life” because it is based on “systemic thinking” or systemic thinking as thinking in relationships, models, and context. In our changing world, the economy must adapt to the constraints and principles of the environment, develop in accordance with the systemic principles of life in stable coordinate systems, using stable universal uniform measurements. According to the theory of complex systems (Thurner et al., 2018), the basic principles of life and functioning of complex socio-economic systems are defined as follows:

- complex systems are usually open to the energy flows, they have a memory and can exhibit properties that produce behaviors which are distinct from the properties and behaviors of its parts;
- complex systems can be nested, the economic system is 'nested' in society and environmental systems and laws are 'higher' than economic laws;
- a complex system is a dynamic network and contains feedback loops;
- the relationship in a complex system is non-linear and a small perturbation can have a large effect, a proportional effect or even no effect.

In many cases, the idea of the complexity of the system is obvious. These include systems consisting of many interacting subsystems. A huge number of relationships leads not only to the complexity of the description, but also to a sharp increase in uncertainty in the dynamics of their development under the influence of the external environment. A fruitful method for describing such systems as a whole is the use of macro parameters, or collective variables, that reflect changes in the entire set of selected subsystems.

The dynamics of the selected subsystem's behavior can be represented as a consequence of the total reactions to certain and random influences, depending on the macroparameters and the vector of the current state of the selected system. Collective variables characterize the coordinated, coherent behavior of systems. It is necessary to single out a finite number of macro parameters, or collective variables, and establish a functional relationship between them. This will show how they reflect the average evolution of the subsystems involved in the formation of the system. All these processes take place and they can be identified at a higher hierarchical level of organization of the entire integrated system. In relation to specific selected subsystems, macroparameters act as control parameters that provide feedback on the impact on specific subsystems, depending on the state of the entire system as a whole. In this case, the dynamics of the system can be modelled as a process in a finite-dimensional space, depending both on the state of the subsystem and on changes in macro variables. Identification of such trends in models allows formulating rules and algorithms that make it possible to achieve the final goal.

Another feature of open dynamical systems is that they do not disintegrate under the influence of strong random influences and retain the defining, vital indicators. For open dynamical systems consisting of a large and constant number of subsystems, an integrated function distributed over time and space can serve as such a conserved indicator. This integrated function has a certain limited number of variables, and its functionality is preserved when any random actions are implemented. The ability to save some functionality is provided by established relations in open dynamical systems.

As macroparameters, or collective variables, within the framework of the socio-economic model are the characteristics of the energy resources (power) flows in the system. These flows include all of kinds energy resource consumption flows, power outputs and energy flow losses.

The integral indicator of the quality of life acts as a preserving indicator, or an objective function, or an integral function.

2.2. A new approach to the analysis of sustainability in the socio-economic systems

Within the framework of the complex system theory, the concept of ecological economics and with aim to formalize the tasks of sustainable development, a methodology for managing sustainability has been developed using the approach of analyzing energy flows (power) changes in open dynamic systems.

Based on the above formulated concepts, in the frame of complex dynamic system and the power changes' analysis approach for the analysis of life open systems (Appendix) is formulated follow:

- The value of total power, useful power, lost power and technological efficiency of the socio-economic system as a basis for constructing an invariant coordinate system
- Quality of life (QOL) per inhabitant in terms of power as a function of the useful power of the socio-economic system (created as a result of activities), life expectancy and environmental quality. The quality of life characterizes the current present state and the potential for development in the future;
- the system of power changes (dN, dP, dG, df) as a dynamic state and direction of development of the entire socio-economic system as a whole.

Based on the basic parameters, it is possible to formulate various socio-economic - natural system development trends (see Table 4.):

1. Growth Zero or stagnation - the absence of growth of the total produced product in a certain period of time, which indicates a positive shift.
2. Growth - an increase in total output, mainly due to an increase in resource consumption rather than an increase in the efficiency of their use.
3. Development - the increase in total output is mainly due to the increase in resource efficiency, not the increase in consumption.
4. Sustainable development - reproduction of innovative development in the long run by introducing advanced technologies and increasing the growth rate of useful capacity in the long run.
5. Degradation - the system cannot ensure the performance of its functions, development is hindered.
6. System collapse - the process of termination of the system.

Table 4. Development trends of socio-economic natural systems depending on changes in the main indicators of power (energy flow) (N (t), P (t), G (t) and f(t))

	Trend of the system	**Trends cod**	**N(t)**	**P(t)**	**G(t)**	**f(t)**
1	Growth Zero	Z	$dN = 0$	$dP = 0$	$dG \geq 0$	$df = 0$
2	Growth	G	$dN \geq 0$	$dP > 0$	$dG > 0$	$df = 0$
3	Development	D	$dN > 0$	$dP > dN > 0$	$dG > 0$	$df \geq 0$
4	Development Sustainable	SD	$dN > 0$	$dP > 0$	$dG < 0$	$df > 0$
5	Degradation	DG	$dN = 0$	$dP < 0$	$dG > 0$	$df = 0$
6	Collapse of system	SC	$N(t) > 0$	$P(t) = 0$	$G(t) = N(t)$	$df = 0$

Source: Authors' representation based on literature review.

All these parameters determine the direction of development of the socio-economic system and can be used as important parameters for assessing external influences. The following factors can be considered as external influences: - factors of digital transformation of socio-economic systems; - development and change of the energy paradigm; - changes in the structure of industrial capital; - changes in the structure of financial capital.

The frame of parameters for sustainable development

Based on the above formulated concepts and the power changes' analysis approach for the analysis of life open systems (Appendix) is formulated and showed in Table 5 the basic framework of universal indicators for identifying and monitoring sustainable development.

Table 5. Framework of universal indicators for sustainable development monitoring

Definition	**Designation**	**Unit**	**Formulae**
Full power (as consumption)	N(t)	Watt	Appendix
Useful power (as production or GDP)	P(t)	Watt	Appendix
Losses of power (losses opportunities or impact on environment)	G(t)	Watt	Appendix
Technological efficiency	f(t)	%	f (t)= P(t) / N (t)
Quality of Life	QoL (t)	Watt /cap	$QoL(t)=U(t)*q(t)*T_A(t)$
Electricity consumption power as part of full power.	E(t)	%	E(t) = N2(t) / N(t)
Labor productivity	HPH(t)	Watt/cap	HPH(t) = P(t) / ML(t) ML(t) – labour
Standard of life	U (t)	Watt /cap	U (t) = P(t) / M(t)
Life expectancy normalized	$T_A(t)$	x	$T_A(t)$= LE (t) /100 LE- life expectancy
Quality of environment	q(t)	x	q(t) = G(t) / G (t - 1)

Source: Authors' representation n

In this paper, the interdependence of the Quality of life QoL(t), productivity of the system PHP(t) and standard of life U(t) under the influence of digital transformation was considered.

3. Data and information

The calculation of sustainable development parameters was carried out using the data of the Central Statistical Bureau of the EU, the World Bank (The World Bank), database of the United Nations[9].

To analyze the dependence of sustainable development parameters and the level of digital transformation, the report data of The IMD World Digital Competitiveness Ranking[10] were used.

The IMD WDCR measures the capacity and readiness of 63 economies to adopt and explore digital technologies as a key driver for economic transformation in business, government and wider society. The structure of the WDCR is built on three factors. The first factor, Knowledge, refers to the intangible infrastructure, which underlines the process of digital transformation through the discovery, understanding and learning of new technologies. The Technology factor assesses the overall context through which the development of digital technologies is enabled. Finally, the Future readiness factor, which examines the level of preparedness of an economy to assume its digital transformation. The following were used as the main indicators: Future Readiness (FUTURE) - the level of readiness of the country for digital transformation; Technology (EDT) - a general technological context that ensures the development of digital technologies; Knowledge (EDK) - the general context of knowledge and education that ensures the development of digital technologies; Digital competitiveness (DC) - competitiveness. The integral indicator of the digital economy (IIDE) was calculated as an average of those indicated above.

As additional parameters were chosen, index of sustainable development and Human Development Index. Index of sustainable development[11]. The Sustainability Index is defined in accordance with the data of the Sustainability Report, which is the first global study that assesses the position of each country in relation to the achievement of the Sustainable Development Goals (SDG). The SDGs set the standard not only for emerging market and developing countries, but also for industrialized countries.

Human Development Index (HDI)[12] was created to emphasize that people and their capabilities should be the main criteria for assessing the development of a country, and not just economic growth. The HDI can also be used to analyze national policy choices, asking how two countries with the same level of GNI per capita can end up with different human development outcomes. The Human Development Index is a summary measure of average achievement in key aspects of human

[9] UNDATA, United Nations Statistics Division. http://data.un.org/.

[10] WDCR (2019), IMD World Digital Competitiveness Ranking report, 2019, https://www.imd.org/centers/world-competitiveness-center/rankings/.

[11] SDR (2019), Sustainable Development Report, 2019, sdgindex.org.

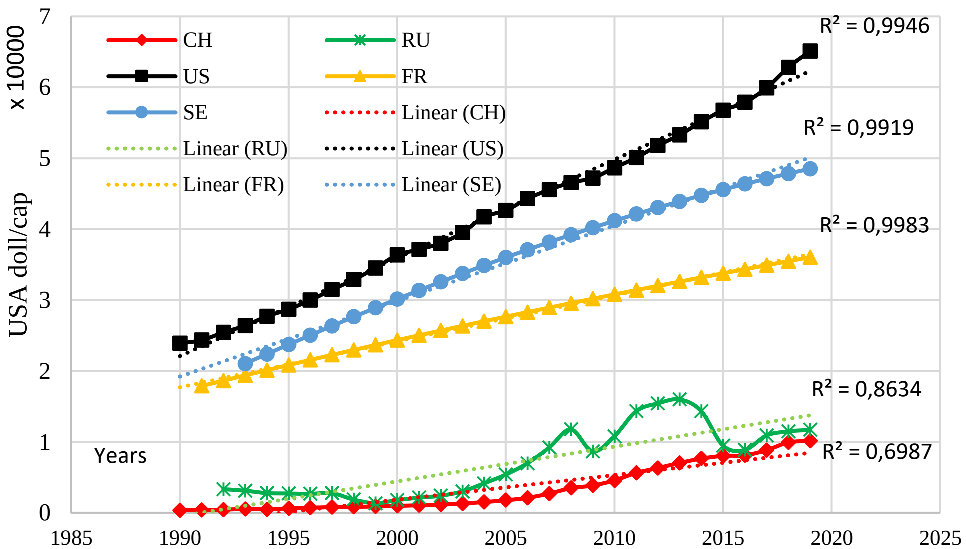
[12] HDI, (2019), Human Development Report, 2019, https://hdr.undp.org /en/content /human-development-index-hdi.

development: a long and healthy life, knowledge and a decent standard of living. The HDI is the geometric mean of the normalized indices for each of the three dimensions.

4.Results and discussion

The calculation and primary interpretation of basic parameters system of sustainability was carrying out for the USA, Sweden, France, China and Russia. The growth of the GDP per capita for the period 1990-2019 is linear tendency for all selected countries with rather high coefficients of determination with values about R^2=0.99 for the USA, France, Swede and about R^2 = 0.70-0.86 for China and Russia (see Figure 1).

Figure 1. Changes of Gross Domestic Capital GDP(t) per capita in the United States (US), Sweden (SE), France (FR), Russia (RU), China (CH) in period 1990-2019, USA dollar/capita x10000



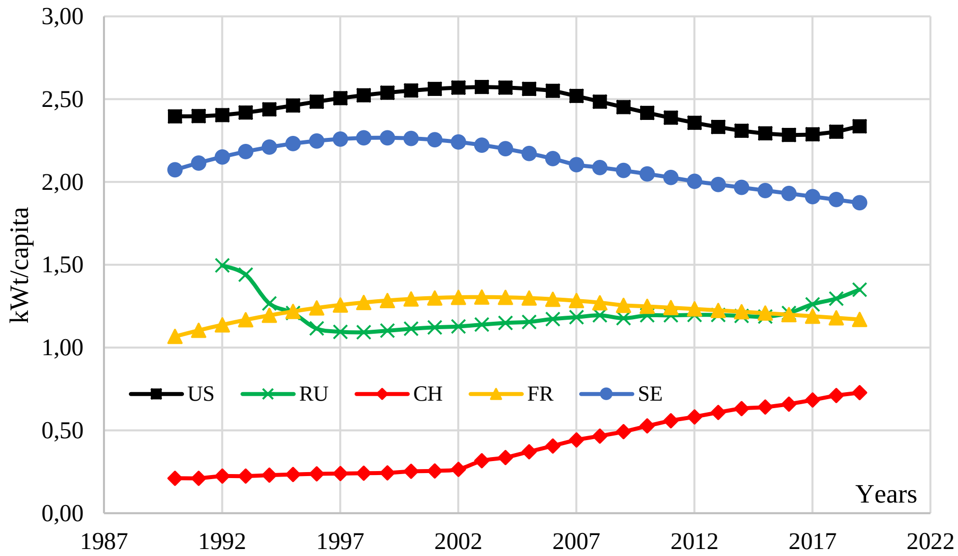
Source: Authors' representation based on EU Central Statistical Bureau and UNDATA data

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 analyze the development of selected countries in the period 1990-2019 (see Figure 2).

The change in useful power per capita or standard of living for countries is non-linear, apart from linear changes for China since 2002. The standard of living in

Russia and France until 2012 has similar values. After 2012, the value for Russia increases, for France it tends to decrease. The calculated parameters of the standard of living for the USA, France and Sweden have a constant value until 2008 and after that there was a downward trend.

Figure 2. Changes of Standard of life U(t) in the United States (US), Sweden (SE), France (FR), Russia (RU), China (CH) in period 1990-2019, kWt/capita



Source: Authors' representation based on EU Central Statistical Bureau and UNDATA data

In accordance with the methodology (Appendix) and the table 5., the main indicators were calculated for the USA, Sweden, France, Russia and China. Countries were ranked according to quality of life indicators (see Figure 6). The United States shows a higher level of quality of life as a potential for development, despite lower other indicators.

The USA, Sweden and France have been on a "Growth Zero" trend for the past 10 years and a decrease in useful power produced per capita. These countries have a lower potential for advanced development with higher productivity, the development of the energy paradigm and the technological level. Russia and China are, respectively, in the stage of Growth and Development and, subject to advanced development, have great potential.

Table 6. The calculated parameters of sustainable development for the United States (US), France (FR), Sweden (SE), Russia (RU) and China (CH) for 2019

N	State	Trend	PHP	QoL	U	E	f1
		n/a	кWt/cap	kWt/cap	kWt/cap	%	%
1	**USA**	Z	4.9	1.8	2.34	21	37
2	**Sweden**	Z	8.6	1.4	1.87	32	42
3	**France**	Z	6.8	1.0	1.17	25	40
4	**Russia**	G	2.6	1.0	1.35	15	33
5	**China**	D	1.4	0.6	0.73	25	37

Source: Authors' calculations

The internal structure of the socio-economic system of Russia and China and their potential as a quality of life (QoL) and productivity (PHP) have been on the rise for the last ten years. The system in this state can more easily and quickly move to the stage of advanced development. The indicators of the share of electricity in the total flow of energy resources E and the technological level of the socio-economic system f1, corresponding to a certain level of the technological platform development, are the high values for the USA, Sweden and France. China's values have increased significantly over the past 10 years and in 2019 have values close to those of the United States.

A study of the level and potential of digital transformation of the economies of selected countries (see Table 7) was conducted using materials from the IMD World Competitiveness Center report, SDG report and HDI data for 2019. All indicators and indicators indicated in the table are numerical values corresponding to a certain place in the ranking. The data of Tables 6. and 7. shows that countries with a higher share of electricity in final consumption (the USA, Sweden, France, China) have a higher level of readiness for the digital transformation of the economy, which is in line with the conclusion of the authors.

Table 7. Indicators of the economic digital transformation, the sustainable development (SDG) and human development index (HDI) for 2019

				The economic digital transformation indies				
№	**State**	**HDI**	**SDG**	**IIDE**	**DC**	**EDT**	**EDK**	**FUTURE**
		x	x	x	x	x	x	x
1	**USA**	926	76	94	100	89	91	98
2	**Sweden**	945	85	91	96	88	90	89
3	**China**	761	72	79	84	73	78	81
4	**France**	901	81	77	82	80	76	70
5	**Russia**	824	74	68	70	59	75	56

Source: Authors' construction, using UNDATA, IMD, HDI and SDR data.

The analysis of correlation (see Table 8.) between calculated parameters of sustainable development, digital transformation indies, human development parameters and sustainable development progress showed:

- high level of correlation of the quality of life with the level of readiness of the country for digital transformation in future (FUTURE), a general technological context that ensures the development of digital technologies (EDT), the general context of knowledge and education that ensures the development of digital technologies (EDK) and digital competitiveness (DC);
- the system productivity (PHP) have high level correlation with a general technological context that ensures the development of digital technologies (EDT);
- human development index (HDI) and sustainable development progress index (SDG) nave a high level of correlation with socioeconomic systems integrated parameters quality of life (QoL);
- the system standard of life (U) have high level correlation with a general technological context that ensures the development of digital technologies
- digital transformation and energy part parameters do not directly show a high level of correlation, but they are indicators of basic changes in improving the quality of life and potential opportunities for development and digitalization

Table 8. Correlation between calculated parameters of sustainable development and economic digital transformation indies on 2019

	HDI	SDG	DC	EDT	EDK	FUTURE
PHP	0.738	**0.800**	0.688	**0.800**	0.682	0.543
QoL	**0.801**	0.726	**0.836**	**0.827**	**0.843**	0.746
E	0.428	0.561	0.575	0.650	0.399	0.567
U	0.767	0.715	**0.814**	**0.800**	**0.835**	0.722
f1	0.407	0.528	0.508	0.622	0.271	0.496

Source: Authors’ calculations

An analysis of the correlation between the quality of life (QoL) and the human development index (HDI) for the period from 1990 to 2019 showed the following results

- a high level of correlation (0.99) for countries with a Growth and Development trend (China);
- a low level of correlation (-0.288) for countries with a Growth Zero trend over the past 10 years (USA, France).

Conclusions

The analysis of the existing state of the problem showed the followings. 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 socio-economic systems.

The introduction of the term "power" in the formulation of sustainable development allows creating an invariant system of coordinates and units of measurement (watts), which allows you to create a measurable relationship between needs and opportunities, as well as a system of indicators and criteria for sustainable development. The new coordinate system in watts allowed to reimagine and analyze the development of selected countries in the period 1990-2019.

Based on the formulated concepts, Quality of life in terms of power is a function of the useful power of the socio-economic system (created as a result of activities), life expectancy and environmental quality. The quality of life characterizes the current present state and the potential for development in the future

The quality of life as an integral parameter, productivity and standard of life correlates with indicators of the economy digital transformation.

Within the framework of the proposed invariant 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 interpreted for the United States, France, Sweden, Russia, China.

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Appendix.

The description of system power changing analysis approach

According to the definitions of the natural sciences, all living systems - nature and society - are open, stable, unbalanced and dynamic systems. And so, it is natural to use the laws of living systems to create sustainable development technologies. There is no closed living system in nature that has no energy inflows and outflows with zero power (energy flow). The law of conserving of energy applies only to systems that are closed to energy flows and cannot serve as an adequate measure of open, living systems.

At present, the inconsistency or inconsistency of the measures of heterogeneous systems (social, economic, ecological, etc.) is the cause of the rupture of links, resulting in social systems being controlled in isolation from the general laws of living systems, ultimately leading to a global systemic crisis. This gap can be bridged by measuring the nature of living systems. According to Bauer (2002), the characteristic of living systems is that they work against the expected equilibrium using free energy. Based on the principle of stable imbalances, the main characteristic of energy flows circulating in living systems is their ability to perform external useful work or work capacity or useful power.

Based on the concepts formulated above, the analysis of sustainable opens socio-economic systems using a power and energy flow approach is based on three main rules:

1. *The principle of energy flow (power) conservation* (Kuznetsov, 2015), which stipulates that, in the process of development of a socio-economic system (as a living open system), the incoming to system energy flow (total power) N(t) during period Δt is equal to the sum of the output useful energy flow (power) P (t) and the power loss G (t), according to equation (1):

$$N (t) = P (t) + G (t) \tag{1}$$

2.*The principle of development conservation* (Podolinsky, 2004; Vernadsky, 2006). The development of the socio-economic system is conserved under the following conditions, that the spatial and temporal dimensions of system quality were maintained and that a continuous increase in full power transformation efficiency φ (t) was maintained, according to equations (2,3):

$$\varphi(t) = P(t) / N(t) \tag{2}$$

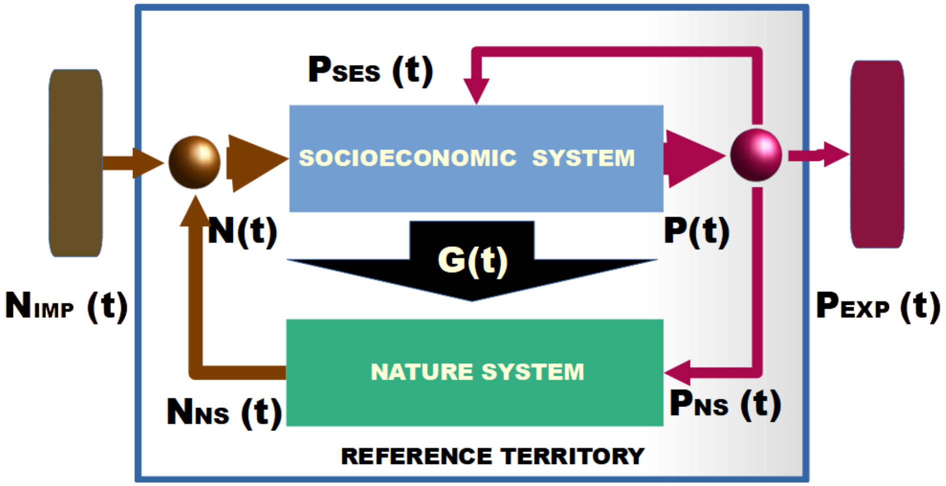
$$\Delta\varphi(t) = d\,\varphi(t) / dt > 0 \tag{3}$$

3.The principle of sustainable development (in power measurements) (Bolshakov *et al.*, 2019). Sustainable development is a continuous process of increasing the opportunities to meet the current needs of the existing socio-economic system in power measurements, without compromising the ability to meet needs for future generations, while increasing the efficiency of using the full power of the system, reducing power losses and not increasing consumption in the face of negative external and internal influences.

The power and flows of energy for life open socio-economic system

From the principle of energy flow (power) conservation, we create a model of power or energy flows for open dynamic socioeconomics system (see Figure 1.). The full power N (t) of the consumed energy resources of the socio-economic system and the rate of change of capacity are a function of the population M (t) and the structure of the economic system. The full power consumption N (t) within the socio-economic system is used and transformed with variable efficiency φ (t) into useful power P (t). Net power P (t) (measure of activities) means the real power or gross product produced that could be used to increase the capacity of the system or to affect the environment. After the N (t) power conversion and transformation, the system loses part of the power G (t) - lost opportunities. The amount of power available to the system is a measure of the potential environmental impact of the system.

Figure 1. The power and flows of energy for open socioeconomic system



Source: Authors' representation based on literature review

The frame of parameters for sustainable development

According to the definition of the socio-economic system (SES), full power (needs or final consumption, potential) N(t) is the input power of total consumption of resources over a given period, expressed in units of power (Watt) and calculated according to formula (4):

$$N(t) = N1(t) + N2(t) + N3(t) \tag{4}$$

Where:
N (t) - full power;
N1(t) - power of fossil fuel consuming (machines, mechanisms and technological processes);
N2 (t) - power of electricity consumption;
N3 (t) - power of food consumption.
The useful power of a SES (gross output or real power) is the total output in watts (Watt) over time. Useful power is determined by the full power utilization efficiency according to formula (5):

$$P(t) = N1(t) * J1 + N2(t) * J2 + N3(t) * J3 \tag{5}$$

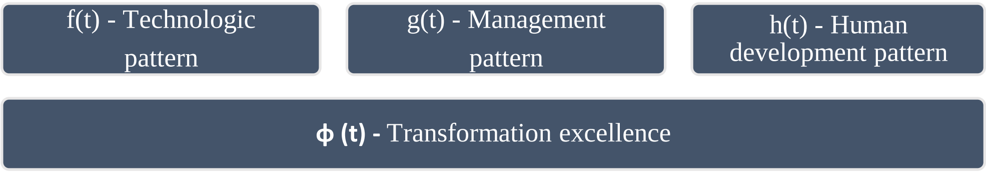
Where: J is energy transformation parameter for specific resources and defined as follows: for fuel J1 = 0.25, for electricity J2 = 0.80, for food J3 = 0.05 (UNSC, 1974; Lindeman, 1942).
SES power losses G (t) is the difference between the total power of the system and the useful power expressed in watts (Wt.), calculated according to formulas (6):

$$G(t) = N(t) - P(t) \tag{6}$$

The technological efficiency of social economic system

The definition of the parameter φ (t) - the parameter of transformation excellence characterizing the efficiency of the use of the full power of the continuous growth of the socio-economic system follows from the principle of preservation of development. The parameter of transformation excellence characterizes the internal structure of the social economic system, and is determined by the rules and parameters of the technological pattern by coefficient f(t), the management pattern by coefficient g(t) and the human development pattern by coefficient h(t) (see Figure 2.).

Figure 2. The structure of socioeconomic system technological excellence parameter



Source: Authors' representation based on literature review.

The transformation excellence coefficient can be defined in general form as a function F, according to formulas (7):

$$\varphi\ (t) = F\ (f(t), g(t), h(t), A_f\ (t), A_g\ (t), A_h(t)) \qquad (7)$$

where A_f, A_g, A_h are coefficients.

The management pattern in general form depends on the planning system, the share of state regulation, the share of monopolies. In a simplified version, it can take two values:
value 0 - if the decision was made incorrectly
value 1 - if the decision is made correctly.
In what follows, we will use the probability of a correct solution.

The human development pattern in general form depends on the education structure and other socio systems factors. As first level coefficients was used human development index (HDI) and sustainable development progress indicator (SDR).

The technological pattern of the socio-economic system in accordance with the proposed model includes three structural parts: energy part, industrial part, digital transformation part (see Table).

Table 1. Technology pattern structure and main parameters

	Part of structure	**Main parameters**
1	**Energy part**	
		Electricity part in final energy consumption
		Hydro-, nuclear energy part in electricity production
2	**Industry part**	
		Industry part in GDP
		High-technology industry part
3	**Digital transformation**	
		Technological content
		Knowledge content
		Future potential
		Competition

Source: Authors' representation based on literature review.

The coefficients of the energy and industrial parts characterize the degree of development of the production and technological platform and the development of the present techno-economic paradigm. The parameters of digital transformation characterize the readiness to move to a new level of sociotechnical development.
The complete system of model's parameters determines the efficiency of the system when transforming the consumption energy flow into useful power.

The parameter of condition to support the system's sustainable development.

The principle of sustainable development is the base for definition of sustainability conditions for the socio-economic system. Thus, a system of sustainable development indicators with a constant power is defined, which characterizes the technological, economic, environmental, social and other possibilities and needs of a complex system. From a methodological point of view, this system is an effective tool for designing sustainable development in the system „man - society - nature". The principle (criterion) of sustainable development is the statement that development is supported in the long run, subject to the following conditions, which can be formalized in the system of equations (8), (9), (10), (11),(12):

$$\Delta N = N - N_0 = \frac{dN}{dt}\Delta t + \frac{d^2N}{dt^2}\Delta t^2 + \frac{d^3N}{dt^3}\Delta t^3 \le 0, \quad \text{and} \quad \Delta N \le 0 \quad (8)$$

$$\Delta P = P - P_0 = \frac{dP}{dt}\Delta t + \frac{d^2P}{dt^2}\Delta t^2 + \frac{d^3P}{dt^3}\Delta t^3 \ge 0, \quad \text{and} \quad \Delta P \ge 0 \quad (9)$$

$$\mathbf{\Delta G = G - G_0 = \frac{dG}{dt}\Delta t + \frac{d^2G}{dt^2}\Delta t^2 + \frac{d^3G}{dt^3}\Delta t^3 < 0, \quad and \quad \Delta G < 0 \quad (10)}$$

$$\boldsymbol{\Delta\varphi = \varphi - \varphi_0 = \frac{d\varphi}{dt}\Delta t + \frac{d^2\varphi}{dt^2}\Delta t^2 + \frac{d^3\varphi}{dt^3}\Delta t^3 \ge 0, \quad \text{and} \quad \Delta\varphi \ge 0 \quad (11)}$$

$$QoL = F(\Delta N, \Delta P, \Delta G, \Delta\varphi) \quad (12)$$

Based on the basic parameters, it is possible to formulate various socio-economic - natural system development trends (see Table 5.):
1. Growth Zero or stagnation - the absence of growth of the total produced product in a certain period of time, which indicates a positive shift.
2. Growth - an increase in total output, mainly due to an increase in resource consumption rather than an increase in the efficiency of their use.
3. Development - the increase in total output is mainly due to the increase in resource efficiency, not the increase in consumption.
4. Sustainable development - reproduction of innovative development in the long run by introducing advanced technologies and increasing the growth rate of useful capacity in the long run.

5. Degradation - the system cannot ensure the performance of its functions, development is hindered.
6. System collapse - the process of termination of the system.