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ASSESSING THE SUSTAINABILITY OF ADVANCED AND DEVELOPING COUNTRIES: A DIFFERENT PERSPECTIVE

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Abstract. *Purpose* – The research aim of the article is the analysis of advanced/developed and developing countries in the context of sustainable development, using invariant coordinate system in energy units, as well as the impact of structural changes in the economy affect the possibility of transition to sustainable development and creation post-industrial society.

Research methodology – In order to achieve the aim were applied the method of socio-economic systems power changes analyzing in the frame of structural economic Kaldor model of GDP and the energy flows models.

Finding – The advanced countries have seen a trend of "zero growth" and a decrease in useful energy production in the last 10 years. These countries have high labor productivity, technological level and diminishing potential for sustainable development. China is in the stage of "growth and development" and has great potential. Data calculated by the authors of the article correlates with the findings of the Kaldor model.

Research limitation – The initial interpretation of the calculated data of France, Germany, Japan, USA, European Union and China was made. Countries have been analyzed in the period from 1990 to 2019. The data of the Central Statistical Office of EU and the World Bank were used.

Practical implications – The results of the study can be used to further planning and design of transition to sustainable development for advanced and developing countries.

Originality/Value – within the framework of the approach, an invariant coordinates system in energy units is proposed and the main parameters for assessing the potential of growth and sustainable development for advanced countries were formed.

Keywords: advanced economics, post-industrial society, sustainability, GDP structure, energy flows, power.

JEL Classification: E19, F69, Q59, R10.

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1. Introduction

The second half of the twentieth century, especially its last quarter, global economic and financial stability has undergone numerous challenges, requiring constant control, rethinking and overcoming. For the past thirty years, it has been marked by a sharp increase in the share of services, the information sector and high-tech industries in the structure of the economies of developed/advanced countries (both terms are used in various sources) (Glazyev et. al., 2018). These structural changes led to the emergence of a popular point of view on the transition of these states to a new stage of its development, which is called "post-industrial society". According to Bell (1973), the main features of the post-industrial society are the transition from industrial production to the predominance of services in the economy, the increase in the role of theoretical knowledge and the intellectual labor working class. The post-industrial economy, according to supporters of this theory, is a natural stage in the development of the economic system, to which, after industrialization, any country should strive for. Indeed, thanks to automation and the international division of labor, advanced countries have been able to concentrate on intangible activities. The growth in the standard of living, the leadership in the creation of information technologies and digital platforms, allowed supporters of post-industrial theory to argue that relative deindustrialization of the economy is the right step for advanced developed countries.

According to the terminology used by the International Monetary Fund [IMF] (2020), advanced economies are a term used to describe the most developed countries of the world. The health of the country's economy is usually determined by indicators such as a high income per capita, the degree of industrialization, a variety of export base, the financial sector integrated into the economy of the world financial system. As of 2020, the IMF classified 39 countries as the countries with an advanced economy, and seven of them as a core of a post-industrial society: the USA, Canada, Japan, the UK, Germany, France, Italy. Nevertheless, the crises of recent decades, the slowdown in the growth of the growth of "post-industrial" economies and the economic successes of the "industrial" countries have led to the idea of restoring the production base of the developed countries of Western Europe, Japan and the United States.

The currently used methods for assessing the sustainability of the development of developed socio-economic systems do not give an objective picture of regional and national development. In the modern changing world, objective indicators of sustainable development of the socio-economic system are necessary for decision-making, all processes should be considered and measured in the invariant coordinate system.

The aim of the article is to analyze advanced/developed and developing countries in the context of sustainable development using an invariant coordinate system in energy units, as well as the impact of structural changes in the economy on the possibility of transition to sustainable development and the creation of a post-industrial society.

The approach considers the method of analyzing changes in the power (energy flows) of socio-economic systems and Kaldor's structural model of GDP, formulates the conditions for sustainable development, determines the main parameters for assessing the potential for growth, development and transition to post-industrial society.

The first part of the paper focuses on key questions concerning the concepts of post-industrial society, traditional description of growth and development in post-industrial countries and current criteria for assessing the advanced economy. In final, authors formulate different point of view on indicators of sustainable development and on formalized problems of the conditions for the transition from an industrial society to a post-industrial one. Within the framework of the concept of natural science approach in economics and taking into account the conclusions of the energy theory of cost, to formalize the tasks of sustainable development, *in the second part*, we consider the methodology of monitoring sustainable development by using the model of socioeconomic system energy flows and structural Kaldor model in context of the systems power changes analyzing method. The calculations and the initial interpretation of the calculated indicators of the largest countries with a developed economy – the European Union, as well as Japan and the United States, which make up the subgroup of the largest countries with advanced economies, was presented *in the third part* of article. Also, for comparison, data on China are presented as country with developing economy.

2. Literature review

2.1. Advanced economy and post-industrial society

The global economic recession and the frequent crises of the modern world increase economic instability, provide a higher level of economic insecurity and cause stagnation (Frankel, 2022). Despite this, our world is capable of producing more material product than any social formation in history. At the same time, the transition to a new techno-economic structure is accompanied by an increasing rate of change and economic instability. Under these conditions of high variability, the importance of sustainable development of countries and regions increases. Modern global trends in socio-economic development are often characterized by such concepts and terms as post-industrial, post-economic society, information society, knowledge society, consumer society, as well as a new service creative economy and some others like them. The post-industrial economy is defined as a period of growth in an advanced economy in which the relative importance of manufacturing declines while the importance of services, information and research increases. Such economies are often characterized by a decline in the manufacturing sector, leading to deindustrialization, and a large service sector, as well as an increase in information technology.

The sectoral aspect of the post-industrial economy is directed to less developed countries that produce what is needed at a lower cost through outsourcing. In the 1930s and 1940s, the economists Clarke, Fourastier and Fischer viewed the decline in the share of manufacturing in the economy as a desirable and inevitable trajectory for the development of modern society (Moraitis, 2022), since economic prosperity was closely associated with the growth of the service sector. They argued that as industrial productivity and incomes increased, labor would become redundant and people would work in services for which demand would rise.

At the same time, the transition to a post-industrial society would guarantee material abundance, leisure, and free people from intense industrial work. Post-industrial economists saw deindustrialization not as a source of concern, but as a sign of progress and successful economic development. It is becoming increasingly clear that the transition of the modern economy to services has created a more precarious economic order characterized by more polarized labor markets, growing inequality and economic stagnation (Benanav, 2020; O'Donovan, 2020).

Deindustrialization did not lead the world community to a post-industrial paradise, but instead brought the state of the world to greater economic insecurity, with dysfunctional labor markets and centuries of stagnation as hallmarks. The development of a post-industrial society in the advanced countries of the world is characterized by the fact that the share of the manufacturing industry in the GDP of these countries is currently lower than in the developing country under consideration.

Data of advanced countries – the USA, Japan, Germany, France, as well as for developing country China in 2019 are summarized in Table 1. The chosen year 2019 is the last year before the beginning of major global changes that will continue in 2023.

Table 1. The sectoral structure of GDP of USA, Japan, Germany, France, EU (European Union) and China in 2019 (source: World Bank, n.d. and authors' calculations)

Country	AG (agriculture, forestry, fishing)	IND (industry, including construction)	INAG = AG + IN (manufacturing (primary and secondary sectors)	ST (services and transports (tertiary and quaternary sectors))
	%	%	%	%
The USA	0.8	18	19	81
EU	1.6	23	25	75
Japan	1.0	28	29	71
Germany	0.8	27	28	72
France	1.5	17	19	81
China	3.0	39	42	58

Obviously, as a result of the relative decline in the share of material production, post-industrial economies have become less dependent on the supply of raw materials. Therefore, it could be concluded that the globalization of the world economy has allowed post-industrial countries with developed economies to transfer the costs of the next global crisis to developing countries.

2.2. Growth and development in post-industrial countries

According to the statements and rules of Kaldor and Baumol (Kaldor, 1967; Baumol, 1967), the weakening of the economic dynamism of the advanced countries is determined by the change in the sectoral composition of modern capitalism, and this is primarily due to the lack of a solid industrial base. In the study of advanced countries, it was stated that there were no high levels of economic growth in the post-industrial period (Table 2). For Kaldor, manufacturing not only has the inherent properties of stimulating economic growth, but more broadly represents a fundamental "growth engine" as productivity growth spreads to the rest of the economy, boosting aggregate productivity and GDP growth (Kaldor, 1996). Manufacturing has the potential to generate important spillovers for the rest of the economy, spurring growth in other sectors and driving technological innovation. Nicholas Kaldor noted in his works a high correlation between the standard of living and the number of resources allocated to production activities. Kaldor's Laws of Growth (Thirlwall, 2003) are a series of three laws concerning the causes of economic growth:

1. GDP growth is positively associated with the growth of the manufacturing sector.
2. Productivity of the manufacturing sector is positively related to growth in the size of the manufacturing sector.
3. The productivity of the non-manufacturing sector is positively related to the growth of the manufacturing sector.

Therefore, structural changes have an impact on real GDP (Baumol, 1967).

Table 2. Socio-economic indicators for the USA, Japan, Germany, France, European Union (EU) and China in 2018–2019 (source: World Bank, n.d.)

Countries	d PX (Change of GDP per capita 2018–2019)	d GDP (Change of GDP 2018–2019)	dM (Change of population 2018–2019)	M (population in 2019)
	%	%	%+	Mln. capita
The USA	1.8	2.2	0.5	328
EU	1.7	1.8	0.1	447
Japan	0.7	0.0	0.0	126
Germany	0.8	1.0	0.2	83
France	1.5	1.8	0.3	67
China	5.6	6.0	0.3	1400

Almost the entire neoclassical theory of economic growth is based on the concept of balanced growth (Barro et al., 2004). The problem is that, from a theoretical point of view, it is impossible to integrate structural changes into the concept of balanced growth. The Solow model (Solow, 1994) is based on the fact that the growth of total output is constant along the entire trajectory of balanced growth. Therefore, models of structural change imply that balanced growth is not applicable in the presence of such changes. This is one of the main shortcomings of neoclassical growth theory, since structural change is one of the well-known empirical facts. Baumol, in his model of an unbalanced economy (Baumol, 1967), confirms the unfavorable nature of the service sector for economic growth. Differences in productivity between the two sectors stimulate an industry shift of resources towards less dynamic sectors, since high productivity activities require less labor to meet existing demand.

While services have historically resisted mechanization, they should not be considered consistently immune to productivity breakthroughs. Recent decades have seen the development of technologies that could potentially overcome some of Baumol's limitations on services, increasing their commercial value and productivity. Digitalization lowers transaction costs and facilitates the provision of services remotely, increasingly exposing them to increased productivity in international trade (Sorbe et al., 2018). Artificial intelligence (AI) is another area of ongoing technological breakthroughs that can further boost the productivity of the service sector (Buzgalin & Kolganov, 2010). However, all of this cannot guarantee that a transformed high-tech service sector will sustainably increase aggregate growth. The McKinsey Global Institute 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 (McKinsey Global Institute, 2018). Production growth 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 had a significant impact on food production and metal smelting. 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.

For the EU, this is a frequent case, including competitive advantages in science-intensive services, high-tech and digitalized sets, participation in the development of production value chains (Boikova et al., 2021). Within place-based approach concept it is important to measure smart growth. Creating an integrated and comprehensive development, the specific of the context or place-based approach with a stress on local assets and knowledge (know-how) is important (Aleksejeva et al., 2020).

2.3. Criteria for assessing the advanced economy

The term "advanced (developed) economy" is used by the International Monetary Fund (2020) to describe the most developed countries in the world. While there is no set numerical convention for determining whether an economy is advanced or not, the general case is for countries that have a high per capita income, a significant degree of industrialization, a diversified export base, and a financial sector that is integrated into the economy of the global financial system. Countries with advanced economies, which are also called developed, industrialized or mature economies, constitute the core of post-industrial society in the hierarchy of world development. The term "advanced economy" is usually used for countries with a decent standard of living, a significant accumulation of industrial capital, modern technologies and institutions that are firmly rooted in the global economy. In 2019, the IMF identified the largest advanced economies as the US, Japan, Germany, France, Italy, the UK and Canada. These countries are also known as large advanced economies or the Group of Seven (G7). The IMF uses the following main criteria to classify countries as advanced economies (IMF, 2020):

1. Gross domestic product per capita (1. PX), which sums up all goods and services produced in a country in one year and divides this number by its population (World Bank, n.d.).
2. The Human Development Index (2.HDI), which quantifies the levels of education, literacy and health in a country in a single figure, as a quick way to classify an advanced economy (United Nations Development Programme, 2019).
3. The volume of international trade of countries (3. EXP) – as an indicator of integration into the global financial system (World Bank, n.d.).

Additionally, the following indicators are considered as parameters:

1. Index of economic complexity (4. ECI) – as an indicator of export diversification. High GDP countries are not considered advanced economies if their exports consist primarily of a few commodities (Harvard Growth Lab, 2019).
2. Quality of life of the population (5. QoL) – as an indicator of the world's largest cost-of-living database NUMBEO which is a crowdsourced global database with information on quality of life, including housing rates, estimated crime rates and quality of healthcare, as well as many other statistics (NUMBEO, 2024).
3. Index of sustainable development (7. SGD) – the index of sustainable development is determined in accordance with the data of the Sustainable development report, which is the first global study and which assesses the position of each country in relation to the achievement of the sustainable development goals (Sachs et al., 2021).

The above indicators for the advanced economies of the USA, Germany, Japan, France, as well as for developing China are presented in Table 3, countries are ranked in descending order of GDP per capita from the US to China in 2019.

Table 3. Advanced parameters for the United States, Japan, Germany, France, China in 2019 (source: World Bank, n.d.)

Country	1. PX	2. HDI	3. EXP	4. ECI	5. QoL	6. SDG
	*	x	%	x	x	x
The United States	65	911	12	15	179	75
Germany	47	942	47	19	187	81
Japan	40	925	17	22	181	79
France	40	903	32	13	158	81
China	10	768	18	10	98	72

Note: * – 1000x US doll/capita.

It can be concluded that developed countries have a high share of services in GDP. However, in the developing country China, all analyzed indicators are lower than the world's first developed economies.

2.4. Different point of view and indicators of sustainable development

In the conditions of a post-industrial society in advanced countries and high volatility, the sustainable development of countries and regions is becoming increasingly important. Zero-loss transformation and nature management, investment-led growth and innovation, an inclusive approach to using human talent to manage insecurity, and a process of international cooperation aimed at achieving common goals – this will be the story of economic growth in the 21st century. The term "sustainable development" was used earlier in nature management, and since the 1980s. began to designate already economic activity within the framework of ecological integrity and eco-efficiency with the aim of the fair functioning of the state, business and society (Trusina & Jermolajeva, 2021).

The current official methodology used to build sustainable development indicators is based on heterogeneous and disproportionate measurements using a normalization procedure. The resulting indicators, as SDG, QoL and HDI (Table 3) are also heterogeneous, as they are backed by heterogeneous values expressed in disparate units, which can generate erroneous estimates and, as a result, inefficient control.

Taking into account the interdependence of socio-economic systems and the natural environment, it must be borne in mind that the coordinate system and units of measurement used in the analysis of the sustainability of economic systems must be independent of various external factors and be constant over time. It can be said that such parameters as GDP or PX (Table 2) in context of the economic structure study, in which the basic unit of analysis of the stability of economic relations is money, seems to be incomplete and inadequate, since the currencies themselves change over time. Additionally, the concept of post-industrial society is poorly formalized and thus the conditions for the transition from an industrial society to a post-industrial one is not sufficiently understood.

The ongoing changes force us to form a new view of the ongoing processes and develop new methods for analyzing economic relations.

3. Methodology

Within the framework of the concept of natural science approach in economics (Capra & Jakobsen, 2017) and taking into account the conclusions of the energy theory of cost (Costanza, 2004), in order to formalize the tasks of sustainable development, a sustainable development management model was developed using the method of analyzing changes in power and energy flows in open dynamic socio-economic systems (Trusina & Jermolajeva, 2021).

The analysis of socio-economic systems is based on the law of conservation of the power of the energy flow (Trusina et al., 2022) in time in energy units necessary for the development and provision of all processes of the socio-economic system – the energy flow (full power) $N(t)$ entering the system over the period Δ t is equal to the sum of the output flow of useful power $P(t)$, as results of activities, and power losses (Formula (1)):

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

There are five main provisions of the model:

1. In the context of the model, *sustainable development* is a continuous process of increasing the ability of the existing socio-economic system in terms of energy units, without reducing the level of generated useful power, to meet current needs, as well as the needs of future generations, while increasing the efficiency of using the full power of the system, reducing power losses and without increasing consumption in the face of negative external and internal influences (Bolshakov et al., 2019).
2. 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 made it possible to rethink and analyze the development of individual countries.
3. *Method for analyzing changes in the power of socio-economic systems*.

The consumed flow of energy or the full power $N(t)$ of society includes all types of energy resources necessary to ensure life, production, technological and other processes according the Formula (2):

$$N(t) = N1(t) + N2(t) + N3(t), \tag{2}$$

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.

This sum of all consumption flows determines the needs or potential of society (Podolinsky, 2004; Bauer, 2002; Shamaeva, 2019).

In accordance with the law of conservation of power of living systems (Trusina et al., 2022), the main goal of the development of socio-economic systems is to increase the amount of useful power $P(t)$, as a result of activity, and reduce losses $G(t)$. The useful power $P(t)$, as gross output or real power, is determined by the full power utilization efficiency according to Formula (3):

$$P(t) = N1(t) \times J1 + N2(t) \times J2 + N3(t) \times J3, \tag{3}$$

where: J – energy transformation parameter for specific resources and defined as follows: for fuel $J1 = 0.25$, for electricity $J2 = 0.80$, for food $J3 = 0.05$ (United Nations Statistics

Commission, 1974; Lindeman, 1942). 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 Formula (4):

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

Intellectual capability is the ability of the system to change the full power by changing the generalized coefficient of technology perfection – $f(t)$ and the quality of planning. The coefficient of technological excellence is determined by Formula (5):

$$f(t) = P(t) / N(t). \quad (5)$$

4. *Useful power of socioecoonomic system $P(t)$ potential for innovative development.*

The development or changes in the socio-economic systems must be ensured by new ideas, projects, technologies or intellectual capabilities, which can be defined as innovations. The concept of formalization of innovations determines that the efficiency of using the full capacity of the system changes (increases or decreases) during the implementation of innovations. Intellectual capacity is the system's ability to change the efficiency of full capacity utilization (transformation). According to the model (Trusina et al., 2022), development management is characterized by expansion into a series of changes in useful power $P(t)$, and represented by Formula (6):

$$\Delta P(t) = P - P_0 = a\frac{dP}{dt}\Delta t + b\frac{d^2P}{dt^2}\Delta t^2 + c\frac{d^3P}{dt^3}\Delta t^3, \quad (6)$$

where: $\frac{dP}{dt}$ – the first derivative is responsible for the growth of the power of the system, a – linear coefficient of t, average growth rate (velocity); $\frac{d^2P}{dt^2}$ – the second derivative is responsible for the development, b – parabolic coefficient of t^2, showing deceleration or acceleration; $\frac{d^3P}{dt^3}$ – third derivative is responsible for the condition of sustainable development, c – impact coefficient.

The minimum time interval for a socio-economic system such as a country or region within the framework of the model is assumed to be 3 years. In accordance with this assumption, the growth of the social and economic system is considered for a period of at least 3 years, development – for a period of at least 9 years, sustainable development – for a period of at least 27 years, which is approximately one generation. The simple form of Formula (6) is presented by Formula (7):

$$\Delta P(t) = P(t) - P_0 = a\,dP(t) + b\,d^2P(t) + c\,d^3P(t). \quad (7)$$

Based on certain parameters, it is possible to formulate various directions for the development of socio-economic (Table 4) and natural systems and can be used as important indicators for assessing internal changes and external influences.

Useful power is a function of the level of technological development of the system and the structure of energy consumption. The formulated concepts are the basis for creating the basic structure of universal indicators for determining and monitoring sustainable regional development.

Table 4. Development trends of socio-economic systems depending on the useful power (energy flow) changes (source: authors' construction)

N	Trend of the system	Trends cod	Period, min. years	$dP(t)$	$d^2P(t)$	$d^3P(t)$
1	Growth Zero	S	9	=0	x	x
2	Growth up	GU	3	>0	x	x
	Growth down	GD	3	<0	x	x
3	Development	D	9	>0	>0	x
4	Development Sustainable	SD	27	>0	>0	>0
5	Degradation	DD	9	<0	<0	x

5. Quality of life in units of energy – QoLE

The quality of life (QoLE) as an objective function in energy units of measurement in the concept of this model is defined as the power necessary to fulfil human needs in order to realize ever-increasing opportunities, taking into account the quality of the environment and the level of technological development. The higher the quality of life, the higher the potential to ensure the development of the socio-economic system through the use of innovations and tools of the digital economy in order to improve the quality of living space for present and future generations (Trusina & Jermolajeva, 2021).

6. The main universal indicators of sustainable development, such as quality of life (QoLE), technological excellence (f) and standard of living $U(t)$ (useful power per capita), productivity as a production of useful power by one employee (*PHPE*), was carried out according to the formulae of Table 5 (Trusina et al., 2022). Data from official databases were used for the calculations, including: population $M(t)$; Life expectancy $LE(t)$; Employees $LM(t)$ (World Bank, n.d.).

Table 5. Sustainable development parameters definition and formulae (source: authors' construction)

Definition	Designation	Unit	Formulas
Full (final consumption) power, Needs or System volume	$N(t)$	W	Formula 2
Useful power, Systems possibilities, innovation level	$P(t)$	W	Formula 3
Power losses, system lost opportunities, environmental impact	$G(t)$	W	Formula 4
Technological efficiency	$f(t)$	%	$f(t) = P(t) / N(t) * 100$
Quality of environment	$q(t)$	%	$q(t) = G(t)/G(t-1) * 100$
Full power final consumption per capita	$D(t)$	W	$D(t) = N(t) / M(t)$
Useful power per capita	$U(t)$	W	$U(t) = P(t) / M(t)$
Productivity	*PHPE*	W	$PHPE(t) = P(t) / LM(t)$
Quality of life	*QoLE*	W	$QoLE(t) = U(t) * q(t) * LE(t) / 100$

All formulated sustainable development parameters are measured in energy units (W – watt) or in relative dimensionless units. As a result, we have defined an invariant coordinate system in energy units.

4. Research results and discussion

Within the framework of the proposed model of socio-economic system's power changes analyzing and Kolder model, calculations were carried out, and the data obtained were presented in the form of tables and graphs. The data of the Central Statistical Office of the EU (Eurostat, n.d.; World Bank, n.d.; UNDATA, n.d.) were used for calculations.

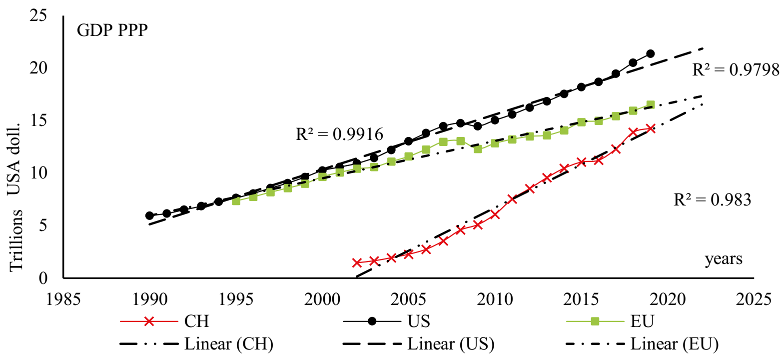

Figure 1. Changes of GDP PPP of the United States (US) and European Union (EU) period 1990–2019, and China (CH) in period 2000–2019 (source: World Bank, n.d. and authors' calculations)

Calculations and initial interpretation of the calculated data of the largest countries with advanced economies – the European Union, including France, Germany, as well as Japan and the United States, which make up a subgroup of the largest countries with advanced economies, were carried out with comparison of China. The growth of the GDP per capita for the period 1990–2019 is linear tendency for USA, EU and China with rather high coefficients of determination with values about R^2 = 0.97 and more (see Figure 1).

The Figure 2 presents the development of the USA, EU and China in the period 1995–2019 in the new invariant coordinate system and energy units of measurement.

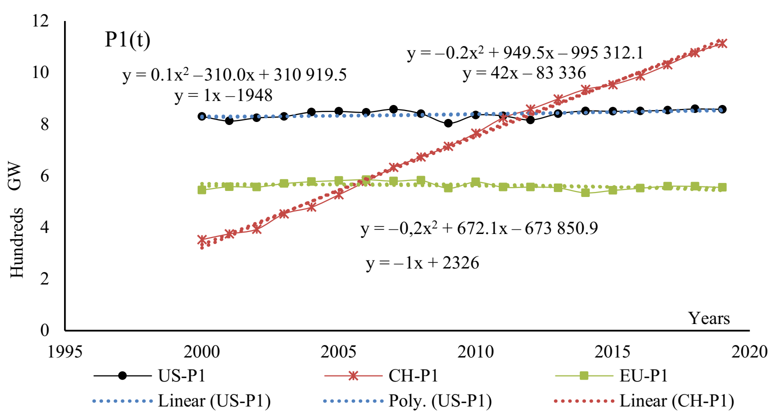

Figure 2. Changes of useful power P(t) of the United States (US), European Union (EU) and China (CH), period 1995–2019 (source: World Bank, n.d. and authors' calculations)

The graphs of changes in useful power for the US and the EU have almost zero changes, over the same period, China had a linear growth with an increase of at least 6%. China's net capacity, which means its innovative development potential, exceeded that of the EU in 2006, and exceeded that of the United States in 2011. According to the presented data on Figure 2 and based on Table 4 conditions, authors formulated various directions of the socio-economic development (Table 6) for the US, EU and China. It is necessary to note the steady growth of China's potential over 20 years from 2000 to 2019 with a high linear coefficient of 42.

Table 6. Development trends for the United States (US), Europe Union (EU), China (CH), period 2000–2019 (source: authors' calculations)

Country	Trend of the system	Period years	Trend's cod	a (Linear coefficient of *t*)	b (Parabolic coefficient of t^2)	dP	d^2P
US	Growth, almost zero, stagnation	20	S	1	0.1 > 0	≈0	>0
EU	Growth, almost zero, stagnation with negative trend	20	S	1	–0.2 ≤ 0	≈0	≤ 0
CH	Growth and Development with a tendency to slow down	20	GD	42	–0.2 ≤ 0	>0	≤ 0

In order to formalize the approach to studying structural changes in the economy the sectoral structure of GDP is represented by the indicator STINA – ratio of non-manufacturing sector share to manufacturing sectors share of GDP bay Formula (8):

$$STINA = ST / INAG, \tag{8}$$

where: *AG* – share in *GDP* of agriculture, forestry, and fishing; *IN* – share in *GDP* of industry (including construction); *ST* – share in *GDP* of services and transports (tertiary and quaternary sectors); The data of *AG*, *IN* and *ST* for selected countries was presented in Table 1 and calculated indicator *STINA* with standard description of society and economy presented in Table 7.

Table 7. Calculated indicator STINA with standard description of society and economy for the United States (US), France (FR), Europe Union (EU), Japan (JP), Germany (GE), China (CH) in 2019 (source: authors' calculations)

Countries	STINA (calculated)	STINA interval for classification	description
US	4.3	4–5	Post-industrial economy and creation of information society. High level of GDP PPP per capita
FR	4.3	4–5	Post-industrial economy and creation of information society. High level of GDP PPP per capita
EU	3.1	3.0–3.9	Transition economy
JP	2.5	2.0–2.9	High-tech production and services
GE	2.5	2.0–2.9	High-tech production and services
CH	1.4	1.0–1.9	Industrial economy

Figure 3 shows the changes in the STINA coefficient for the USA, EU and China for the period 1995–2019.

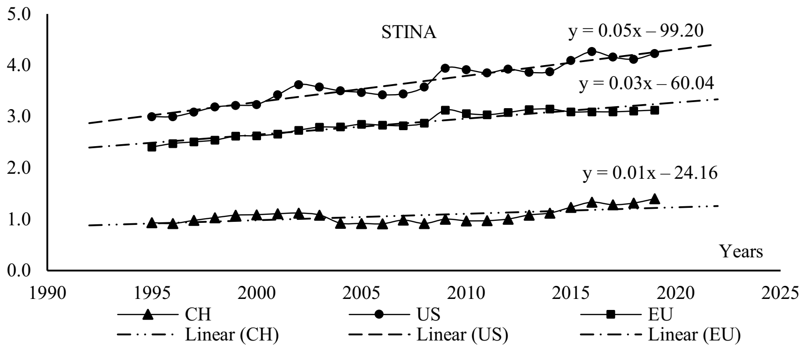

Figure 3. Dynamic of coefficient STINA changes for the United States (US), European Union (EU) and China (CH), period 1995–2019 (source: World Bank, n.d. and authors' calculations)

Comparing with the results of Figure 2, the authors can draw the following conclusions:

- if the value of STINA is in the range of up 2, its change over time is insignificant (less than 5%), we can talk about steady-state economic growth (example of China);
- if the STINA is outside 2, we can talk about slow or zero economic growth (example of USA, EU);
- if STINA change over time is significant, it is connected with economic reconstruction and as results then this slows down the growth.

In accordance with the methodology and Table 5, the main indicators were calculated for the USA, France, Germany, Japan and China. Countries were ranked according to quality of life indicators (see Table 8). The United States shows a higher level of quality of life as a potential for development. At the same time, advanced countries with a high STINA coefficient (more than 2) have reduced their development potential in future (d QoLE) and productivity (d PHPE), and China has a threefold increase in the possibility of further development.

Table 8. Sustainable development parameters for the United States (US), Japan (JP), Germany (GE), France (FR), China (CH) in 2019 (source: World Bank, n.d. and authors' calculations)

Systems	D(t)	U(t)	f (t)	QoLE	d QoLE (Change for 2000–2019)	PHPE	d PHPE (Change for 2000–2019)	STINA
	kWt	kWt	%	kWt	%	kWt	%	x
US	6.6	2.3	36	1.8	–14	4.9	–8	4.3
FR	3.2	1.3	40	1.0	–5	3.0	00	4.3
GE	3.5	1.2	36	1.0	–4	2.5	–20	2.5
JP	2.8	1.2	41	1.0	–9	2.2	+12	2.5
CH	2.1	0.8	37	0.6	+200	1.4	+180	1.4

Data of Tables 6 and 8 show that:

The United States shows in 2019 a higher level of quality of life (QoLE) as a potential for innovative development and high level of STINA, that is corresponding of the development trends. Problem is there in negative tendencies if changes of QoLE and PHPE. This is possibly the influence of a relatively low technological efficiency coefficient f (t). The US have been on a "Growth Zero" or Stagnation trend for the past 10 years and a decrease in useful power produced per capita.

France shows in 2019 a higher level of STINA and the relatively high level of technological efficiency coefficient f (t), but at the same time it has a low level of quality of life (QoLE) as a potential for innovative development. In the previous stage of industrial development, France did not accumulate the corresponding potential.

Germany and Japan show similar indicators, but Japan has a higher level of technological efficiency f(t) and a positive trend in productivity.

These countries have a lower potential for advanced development with higher productivity, the development of the energy paradigm and the technological level. China is in the stage of "growth and development" and has great potential due to advanced development. The internal structure of the socio-economic system of China and their potential as a quality of life (QoLE) and productivity (PHPE) 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. China's values have increased significantly over the past 10 years and in 2019 have values close to those of the United States.

It is important to note that the data calculated by the authors of the article in the invariant coordinate system in energy units in structural indicators correlates with the findings of the Kaldor model.

5. Conclusions

Within the framework of the concept of natural science approach in economics, a model of sustainable development monitoring using the method of analysis of energy flows and power changes in open dynamic socio-economic systems has been developed to formalize the tasks of sustainable development.

The authors presented the results of the analysis of advanced/developed countries and compared them with a developing country in the context of the proposed approaches.

Within the framework of the study, using the invariant coordinate system in energy units and the main provisions of the Kaldor model, the basic indicators of socio-economic systems and the STINA structural change coefficient were developed.

The data calculated by the authors in the invariant coordinate system in energy units and the analysis of GDP of post-industrial economies of leading countries showed the non-linear nature of GDP and GDP per capita growth in these countries.

The indicators were calculated and interpreted for developed economies – the United States, France, Germany, and the European Union – and compared with data for China as an emerging economy.

Based on the new definition of sustainable development in energy units and the method of analyzing the change in the power of socio-economic systems, the historical development trends of the USA, EU and China for the period 1995–2019 were formulated.

The results of the study can be used for further design of sustainable development of developed and developing countries.

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