Systemic Socio-economic Essence of Sustainable Transportation of Energy[1]

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DOI: https://doi.org/10.32782/2707-8019/2024-1-2

Abstract. *The purpose of the article is the analysis of the systemic essence of sustainable transportation of the energy system, based on the mass implementation of renewable energy sources and efficient energy storage systems. At the same level as the analysis of the transformation processes of energy assets, the accompanying components of the specified transformation process are revealed and analyzed: transition to horizontal distributed energy networks, development of social and solidarity economy, dematerialization and sustainable transportation of economic systems, convergence and miniaturization of assets,*

[1] The publication was prepared in the framework of the research project 0122U001232, "Restructuring of the national economy in the direction of digital transformations for sustainable development", funded by the National Research Foundation of Ukraine

electrification of transport, hydrogen vehicle implementation of energy systems, cyberization control over the work of systems, systematization of public institutions. Analyzing the conducted research, the authors draw important conclusions. The energy sector, in which 2/3 of the processes of harmful impact on the environment are generated, is a key area of solving the problems of sustainable transportation of the economy. Sustainable transportation of the energy complex is possible only if adequate transformations of the socio-economic system are carried out. The specified transformations mutually condition each other and can significantly strengthen the sustainable potential of restructuring the energy complex, achieving a general synergistic effect. The transition to renewable energy systems requires constant innovation. Today, technological solutions of the near future should be actively developed in the scientific sector. The full potential of the mentioned energy transition can be realized only under the condition of appropriate institutional support and active international cooperation.

Keywords: *renewable energy, energy storage, sustainable transportation, horizontal networks, dematerialization, cyberization, electrification of transport, hydrogen vehicle implementation, synergistic effect.*

JEL Classification: *O13, L91*

1 Introduction

The world is currently in a phase transition to a new socio-economic formation, which can be tentatively called *the sustainable economy.* The key feature of such an economic system is sustainable transportation (harmonization) of relations between society and nature. Sustainable economy has a multifaceted character. Depending on the view of these aspects, it can also be called "green" (because production systems are being greened), informational (information becomes the main means of production and an object of consumption), additive (additivity becomes a key technological principle), social (the main goal is the social development of a person), knowledge economy (acquiring new knowledge becomes the main goal and the main source of social development), network economy (a transition from industry vertical connections to horizontal network communications is taking place), etc.

In any society, the processes of obtaining and consuming energy remain the basic foundation that ensures the functioning and development of social systems.

However, the energy sector attracts our attention for one more reason. According to various estimates, about ¾ of greenhouse gas emissions are generated in the energy sector. Therefore, the processes of energy production and consumption are the area where human efforts should be primarily directed for the greening of the economy and solving the problems of the global environmental crisis.

Sustainable transportation of the energy complex is a complex not only technological, but also socio-economic phenomenon. It requires solving organizational, economic and institutional problems. A significant number of scientific works are devoted to these questions: HIS Markit, 2020; The costs, 2019; Bellini, 2020; Delbert, 2020; Dudleg, 2019; Hunt, 2020; Will solar, 2020; Mokhtar, 2019; Kellner, 2019; Outlook, 2020; Net, 2021; Acri, 2022).

2 A systemic view of sustainable transportation of the energy complex

Now, in the issues of greening of energy, the main attention is focused on the introduction of alternative (renewable) energy sources. However, sustainable transportation of the energy complex is a much more complex socio-economic phenomenon. The use of alternative sources (in particular, SPPs, WPPs, etc.) in combination with energy storage systems is, relatively speaking, only the "tip of the iceberg" of "green" energy. Among the less obvious, it should be noted, first, the transition to horizontal network systems of energy production and consumption, dematerialization, and sustainable transportation of economic systems, etc., which is conventionally shown in Figure 1.

It should be noted that the indicated vectors of sustainable transportation of the energy complex are not separate links of the economic complex, but subsystem entities of a complete economic system. Their interrelated and mutually conditioned connections form energy effects that influence the sustainable development of civilization on the planet. Let's try to analyze the systemic essence of the emergence of the specified effects.

Development of renewable energy sources. Currently, the locomotives of innovative development of renewable energy sources are solar and wind energy. Due to their negative impact on landscapes, hydroelectric power plants have limited prospects for development (only in mountainous regions and also with the use of mini-hydroelectric power plants). Processes of obtaining energy from biogas, biofuel, heat pumps, geothermal and wave power plants also have a commercial level of use.

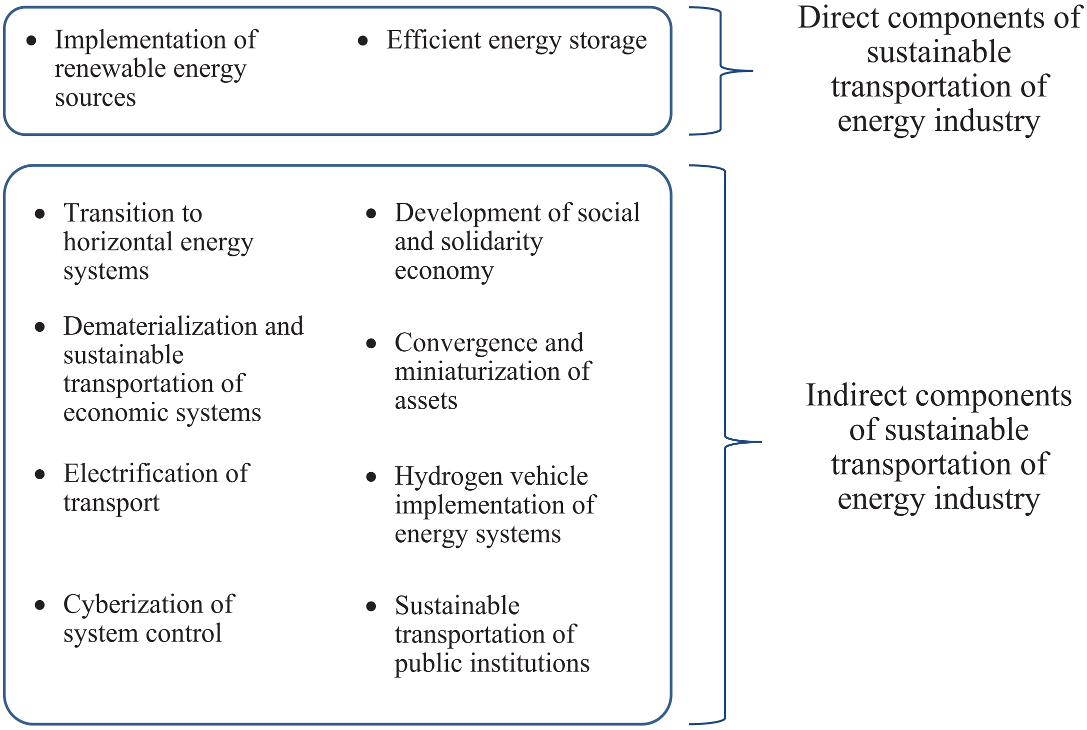

Figure 1 Direct and indirect components of sustainable transportation of energy industry

Applied application of energy utilization processes of various fields, types of movement, and chemical processes begins.

The development of renewable energy is taking place in the following directions:

– increasing the efficiency of existing technological solutions (in particular, PV solar panels, having an average efficiency of only a few percent in the 1950s, increased this indicator in recent years to more than 20%; and in scientific studies, this indicator approached 40% – Swarc, 2022; Essing et al., 2017);

– diversification of technological principles of construction of renewable energy generators; there is a wide range of opportunities for obtaining renewable energy, in particular, the following energy sources are used: energy that the planet receives from space (the sun, tides); geothermal energy of the Earth; the energy of physical fields (in particular, WISP generators using electromagnetic waves); energy of primary natural movements (wind, hydro, waves); the energy of secondary man-made movements (utilization of the movement energy of mechanisms and people); energy of different temperature and pressure potentials (heat and wind pumps); energy of chemical processes (biogas, various chemical reactions);

– integration of energy sources into objects and things of human life (buildings, furniture, clothes, other things);

– increasing the share of renewable energy produced in private households.

The development of renewable energy over the past 10 years has allowed it to make tremendous progress, which is illustrated by the figures in Table 1.

The dynamics of the development of renewable energy creates prerequisites for its progress in the future, as evidenced by the indicators in Table 2. At the turn of 2015–2016, the specific cost of electricity production from renewable energy sources and from traditional fuel energy became equal. In the future, we should expect an increase in the gap according to this indicator in favor of renewable energy.

Efficient energy storage. This direction of development of technological systems makes it possible to eliminate contradictions in time between when energy can be obtained and when there is a need to use it. The need for energy storage will grow as renewable energy sources develop. In particular, the sun and wind are not always present. And while they are there, it is necessary to take advantage of the situation – to produce energy, although at this time there will be no need for it... However, it is advisable to do this only if a person has at his disposal reliable batteries that allow you to accumulate and store energy in unlimited quantity.

Today, five main directions can be identified, which in one way or another promise to become promising for their commercial development:

Table 1 Dynamics of "green" energy production in the world (compiled by the authors based on sources: Bellini, 2020; Cost, 2020; Delbert, 2020; HIS Markit, 2020; Hunt, 2020; Moktar, 2019; Solar, 2020; Will Solar, 2020)

Indicator	Year	
	2010	2020
Production of solar (PV) energy in the world, GW	23	627
Multiplicity of growth, times	–	27
Share of renewable energy (including hydro), %	5	30
Specific cost of solar energy (PV), USD / kWh	0.37	0.06

Table 2 Forecast indicators of the dynamics of the development of solar energy until 2050 (compiled by the author based on the data of: Will Solar, 2020; Net Zero, 2021)

Indicator	Value
Expected decrease in the average specific cost of PV modules, %	63–75
Specific cost of 1 kWh of solar (pv) energy, USD / kW · h	0.020–0.025
The share of solar energy produced in private households in the total volume of solar energy produced in the world, %	11 a.m. to 3 p.m
The share of renewable energy in global electricity production, %	50–65
The share of renewable energy in the growth of new capacities electricity generation, %	85–90

– *hydroaccumulation* (related to natural and artificial raising of the water level in periods of excess energy production and utilization of accumulated energy in peak periods);

– *electric storage* – the energy efficiency of modern storage batteries reaches 80–90%, they withstand from 2000 to 10000 charging cycles (5 different, 2019); mileage of modern ordinary electric cars on one charge reaches 600–700 km, and pilot copies 1000 km; the new charging time reaches 40 minutes (Capata et al., 2022; Simpson, 2022);

– *thermal accumulation* – thermal solar generators work on this principle; in particular, active elements (for example, salt shears) are heated up to 500°C by the sun's rays during the day; thanks to this heat, the generator produces electricity even at night;

– *chemical accumulation* – associated with a purposeful change in the properties of substances due to an excess of energy or the accumulation of organic substances with subsequent production of biogas or electricity; in particular, a chemical battery based on norbornadiene (norbornadiene) is able to store most of the thermal energy from sunlight in its chemical bonds from several months to several years (Petersen et al., 2019);

– *hydrogen technologies* – are a type of chemical accumulators and make it possible to convert excess "green" energy into hydrogen production due to the electrolysis of water.

The colossal progress of energy storage technologies has made it possible to reduce the specific costs of storing 1 MWh of electricity in half – from USD 300 to USD 150 (Cost, 2020).

In the leading countries of the world, at the end of the 2020s, it was legally recommended to install renewable energy sources only with energy storage systems (Spieth et al., 2022). This gave a start to the construction of large-scale energy storage systems. In 2022, the global market for energy storage systems was estimated at 4.7 billion USD. For 2026, the indicated indicator is forecasted at 12.9 billion USD. About 20 leading manufacturers of energy storage systems offer their products on the market (Battery, 2022). As of 2020, about 10 large-scale industrial energy-saving systems have already been put into operation in the world in Australia, China, Canada, and the USA (Vashchenko, 2020).

DNV estimates Energy Transitional Outlook, 38% of all electricity in the world in 2050 will be produced from the sun (pv). A third of the specified capacities will be equipped with energy storage systems (Long, 2022).

The development of energy storage technologies in the future (Table 3) creates prerequisites for a significant increase in the efficiency of the functioning of the energy complex.

Mass use of energy storage systems can bring great economic, social and environmental (sustainable) effects. According to the estimates of the UK government, the introduction of energy storage systems provides the application and integration of low-carbon technologies into industry, heat recovery, and significant effects on transport. All together can bring an economic effect

Table 3 Forecast indicators of the development of energy storage technologies for 2040 (compiled by the authors based on: Net Zero, 2021; Vashchenko, 2020; Will Solar, 2020)

Indicator	Value
Reduction of the specific cost of large-scale energy storage systems, %	65–75
Total installed capacity of large-scale energy storage systems, GW	1100
Total electricity storage potential, GWT-h	2850

(savings on energy costs) of ₤40 billion (48 billion) by 2050 USD), which is equivalent to paying such amount of people's energy bills (What, 2022).

Transition to horizontal energy systems. The transition to renewable energy sources simultaneously conditions the transition to new principles of production organization. Such principles are implemented through horizontal distributed networks of the formation of energy systems. In fact, we are talking about the transition from a small number of large energy producers to a huge number of small energy units decentralized in space. On the scale of the EU, we can talk about a figure of hundreds of millions. It is this value that measures the number of buildings, each of which is expected to be converted into a source of alternative energy (solar, wind, biogas, obtained with the help of heat pumps).

There is a need to solve an unprecedented complex of technical, organizational and economic tasks related to the production, collection, transformation, storage, transportation and consumption of energy. The creation of EnerNet, a network electrical infrastructure, is aimed at solving these tasks.

The author of the term “EnetNet” (Ether net) (by analogy with the “Internet”) is considered the American engineer and inventor Robert Metcalf (Robert Metcalfe), who in 1973 laid out the concept of the future global energy network, which should connect distributed renewable resources, “connecting individual consumers to them and thus contributing to an increase in the standard of living” (Patterson, 2017). In 1983, the non-profit organization IEEE (Institute of Electrical and Electronics Engineers) approved EnerNet standards (Robert, 2014).

The global Internet network, which today has become an integral part of the life of the Earth’s inhabitants, ensures the performance of a whole set of functions related to the processing, transmission, storage and reproduction of information. Metcalfe's idea was precisely to endow energy networks with such a set of energy-related functions. For this, energy networks must become truly “smart”, that is, capable of solving a significant number of information tasks in an automated (computerized) mode.

To be specific, EnerNet is designed to ensure the following groups of functions: *generation and transformation of energy, its tariffing, collection (purchase) of energy, transmission, storage and sale, control over ongoing processes (monitoring); optimization of operations, ensuring the stability and security of systems, maintaining the quality of electricity.*

It is necessary to pay attention to the fact that such systems must ensure two-way exchange of electricity and information flows, because the producer and consumer of energy (and they can be ordinary households located in different territories) can constantly change roles. And the person who just a few minutes ago was producing energy can, due to a number of reasons (weather conditions, work mode, etc.), turn into its consumer. Undoubtedly, the reverse transition should be just as easy. It is about the fact that all objects of the energy network should be transformed from passive to active. Active energy networks, able to quickly adapt to the changing needs of interested parties – owners, consumers, sellers – are considered today as a key element of the infrastructure of "smart" energy systems of the future.

Another important task, to be solved by EnerNet, is the integration into the work of other “smart” networks (smart grids) that are being created today at the level of enterprises, territories, and countries. Actually, EnerNet is a form of one of such “smart” networks, which allows it to organically fit into the general picture of the formation of the global information space.

It should be emphasized that EnerNet is not only new energy technologies, but also modern information and communication technologies *of billing* (that is, economic calculations), *e-commerce, access control* and *administration* in networks of various scales, *modeling and data storage, virtualization, computer security, distributed computing, collection, processing, and transmission of information* in real time.

The development of “smart” information and energy networks will significantly increase the efficiency of energy production and consumption processes, as well as ensure the quality of energy supply and the stability of energy systems.

Finally, the transition to "smart" energy systems will give impetus to the development of new types of products and services, as well as to the formation of new markets.

It can be noted that as the regional EnerNet networks develop, first on the scale of the European Union, the USA, India, China, and other large countries, and then on a global scale, a kind of global "energy" Internet will be fully formed. For the successful integration of a wide range of technological, general technical, project, organizational, management and logistics solutions, such an "energy" Internet should develop based on open, publicly available standards recognized by the industrial and management communities. The world system of such standards is now rapidly developing.

In EU countries, distributed generation already accounts for more than 10% of the total amount of energy produced, and in Denmark this indicator is about 50%. More than 12 million installations of small, distributed generation with a total installed capacity of more than 220 GW are in operation in the USA, and the growth rate is an average of 5 GW per year. Several industrialized countries (EU, USA, Australia) have recently adopted conceptual documents on the development of the industry with a stronger emphasis on small-scale energy. In the EU, it is the EU Directive 2004/8/EC dated 11.02.2004 "On the development of cogeneration based on useful heat in the internal energy market" (Lajoie, 2018; Smart, 2022). Annual investment in distributed energy networks should increase from USD 260 billion in 2020 to USD 820 billion in 2030 (Net Zero, 2021).

All this indicates that the relevance of the development of "smart" energy systems will grow every year.

Development of social and solidarity economy. The formation and development of horizontal distributed production systems determines the emergence of a new type of socio-economic relations, which lay the foundation for the formation of a corresponding type of economic systems, which was named the social and solidarity economy (SSE). In SSE, the achievement of economic, social and environmental goals is perceived by all participants of the production-consumer network as a common property. According to its organizational principles, the SSE is significantly different from the command economy systems of the so-called "socialist" type, built on state ownership. SSE also differs from systems formed on private property, which function on the basis of competitive entrepreneurship in market conditions. It is not by chance that CSE is called an economic system of the third type, or "third sector".

The functioning of production networks has its own specific features that determine the behavior of their participants (Sahakian, 2016; Social, 2017):

– all network participants have equal rights and responsibilities within the network's functioning;

– in contrast to the systems of command economy or capitalist entrepreneurship, where the performers act as hired workers, in SSE the participants are free owners of the means of production that they own and with which they enter the network; at the same time, they both bear the necessary costs, having joint responsibility for their own participation in the functioning of the network, and have equal rights to receive their joint share of benefits and results (economic, social, environmental) from joint activities;

– unlike the public sector, in which organizational influence (setting goals, forming tasks, and often choosing means) occurs from the top down, in SSE it is carried out on the basis of joint decisions of network participants – horizontally, with the coordination of the democratically elected management team, to which the "network" delegates management powers;

– unlike capitalist structures, where profit maximization is a priority, in SSE participants are forced to harmonize economic results (in particular, income and profit) with social and environmental effects, because participants simultaneously act as both producers and consumers of results, including social and environmental;

– the work of each network is based on the principles of voluntariness, self-organization, self-management, autonomy (each organization chooses its own principles and adopts its own rules);

– prerequisites are created for the development of multifaceted forms, flexibility and dynamism.

Existing signs of the formation of SSE structures can be traced in the solar energy sector, where the most relevant conditions for this arise. According to the Bloomberg company forecast New Energy Finance, it is expected that in 2050 the share of solar electricity (pv), which will be produced in private households, will reach 11% (Will solar, 2020). However, there are countries where this indicator is already higher even today: Australia (24%), Brazil (20%), Germany (15%), Japan (12%), Ukraine (12%) (Azhgalieva et al., 2022).

Dematerialization and sustainable transportation of economic systems. The production of any materials in one way or another involves the use of energy and the impact on the environment. Therefore, any relative decrease in the material intensity of the performance of a unit of certain functions by the material assets of the economic system directly or indirectly leads to a decrease in the load on the biosphere and sustainable transportation of the activity of the economic system.

Conventionally, such a relative reduction in the material intensity of certain functions of the economic system is called *dematerialization.* Scientific and technological progress steadily leads to the dematerialization of economic systems. The pace of this phenomenon has accelerated with the intensification of digital transformations and the beginning of the implementation of Industry 3.0 and Industry 4.0.

During the last decade of the 20th century and the first decade of the 21st century, the weight of photo and video cameras, tape recorders, and batteries decreased several times, and even by orders of magnitude. Over forty years, the fuel capacity of cars has decreased almost 10 times (from 20 to 2 liters per 100 km) (Weizzekker et al., 2000; Weizzekker et al., 2013). The transition of the photo and film industry to digital technologies rendered unnecessary the entire industry engaged in the production of photo and film materials (film, paper, chemical reagents). In addition, the production of equipment necessary for developing, fixing, and printing the corresponding products became unnecessary. The obvious consequence of these processes is the bankruptcy of the world-famous company “Kodak”, which has served the market of photographic materials well for more than a hundred years.

It is possible to single out several areas of development of economic systems that ensure a reduction in the resource intensity of their functioning:

– measures for large-scale resource conservation (in particular, thermal insulation of buildings, use of less energy-intensive equipment, etc.); an example is the application of the “Zero – energy – building” concept in construction:

– use of resource-saving technologies;

– use of effective resource-saving work modes;

– the use of environmentally friendly technologies that reduce environmental consequences and related costs;

– replacement of material substances with information (in particular, transportation and storage of not material things, but their digital counterparts);

use of materials with new properties.

A purposeful change in the properties of materials is an extremely effective way of saving resources, because it allows you to influence the resource intensity of the entire economic system. In particular, it makes it possible to reduce the resource intensity of production systems at three stages: during the production of raw materials, the production of the material itself and its use in technical systems.

For example, thanks to the introduction of fiber – optic communication (quartz, glass, or polymer fiber), it was possible to increase the speed of information transmission by more than 5 orders of magnitude. One optical fiber can easily replace an entire cable containing several hundred metal wires. A single optical fiber with a diameter of about 1.5 cm can successfully replace a 7.5 cm diameter telephone cable containing 900 pairs of copper wires. The light guide also has several other significant advantages (Harris et al., 2022).

In addition to the fact that new materials with their incomparably higher functional properties allow replacing several expensive and resource-intensive (during their production) materials, they, as a rule, also significantly (often by orders of magnitude) reduce the resource intensity of the functions performed by them.

In particular, the heat flow during signal transmission in communication channels with fiber LEDs is approximately 100 times less than the heat flow during signal transmission over nickel cables (Fiber, 2022).

Convergence and miniaturization of assets. One of the key methods by which dematerialization is achieved is *convergence*.

Convergence involves combining several properties and functions in one object or device for further use of this device for different purposes. Thus, convergence usually means *multifunctionality*.

One of the products of convergence is carried by every modern person. This is his mobile phone, which accommodates everything that a few years ago was a separate, and rather bulky object: a computer, phone, camera, video camera, flashlight, notebook, clock, alarm clock, calendar and much more (Figure 2).

However, carriers of such functions that previously did not exist at all should appear in this list, for example: “e-mail operator” or “personal memory stick”.

Convergence relates to another phenomenon of dematerialization – *miniaturization.* Miniaturization can be both a prerequisite and a consequence of convergence.

Miniaturization is a phenomenon of changing the material component (overall dimensions, mass, energy consumption) of certain assets (devices, mechanisms, machines, consumer goods, etc.) while simultaneously improving their functional properties (productivity, reliability, number of performed functions, etc.).

Already today, the scale of miniaturization is impressive, in particular, in electronics. At present, the power of hundreds of thousands of transistors is concentrated in one grain of an

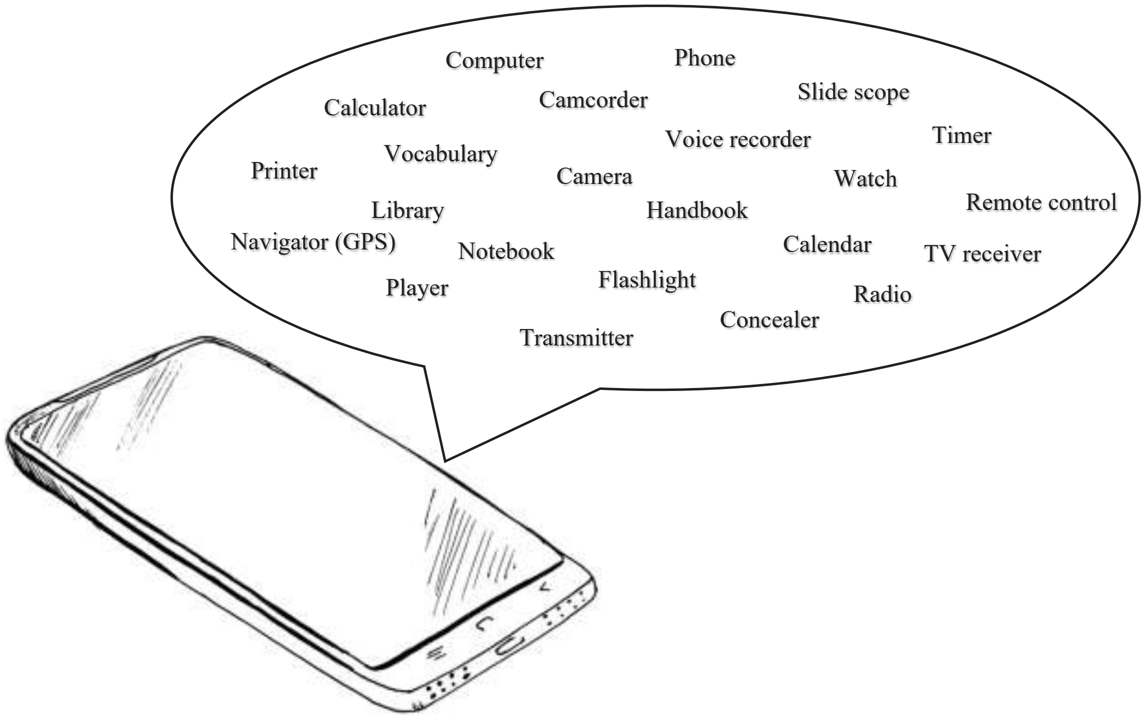

Figure 2 Functions of an ordinary mobile phone (weighing no more than 200 g), which were previously performed by extremely material-intensive and energy-intensive objects (weighing tens of kilograms in total)

integrated circuit costing a few cents, together with all the accompanying fittings. With the development of nanotechnology, we can expect the appearance of a computer the size of a molecule (Impact, 2021).

As a result of the dematerialization of economic systems and the miniaturization of economic assets, a significant decrease in the energy intensity of a unit of GDP should be expected, which is shown in Figure 3.

Electrification of transport. The transition of transport systems to electric power will make it possible to solve a whole set of economic, ecological and social problems. The main effects can be formulated as follows:

– public costs related to the functioning of transport systems are reduced; in particular, entire industries related to production, processing, transportation and storage of fuel are excluded from economic activity; accordingly, the related public costs are reduced;

– the impact on the biosphere, related to obtaining fuel and the functioning of transport systems, is significantly reduced;

– prerequisites are being formed for the development of various forms of sharing relationships in the operation of vehicles and the widespread introduction of unmanned transport (Net Zero, 2021).

An 18-fold increase in sales of electric cars is expected in 10 years – in 2030, compared to 2020 (Net Zero, 2021). Accordingly, the infrastructure for the service of electric transport should be significantly developed, and the infrastructure of traditional types of transport will gradually decrease. The number of public charging points for electric cars should increase from 1 million units (in 2020) to 40 million by 2030.

Hydrogen vehicle implementation of energy systems. The use of hydrogen in energy systems can have significant economic and environmental effects. In particular, hydrogen can create a "bridge" between traditional and new technologies, acting as an energy carrier (and clean). Hydrogen can also act as an active element of energy storage, thereby taking on the functions of both an energy carrier and a battery.

A significant problem of the mass use of hydrogen is the economic inefficiency of implementing the full cycle of obtaining and using hydrogen within the limits of traditional energy technologies. To obtain hydrogen during the electrolysis of water, it is necessary to spend twice as much energy as can be obtained during its combustion.

This problem can be solved only by using excess energy from renewable sources (such hydrogen is called "green"). The limits of the use of hydrogen

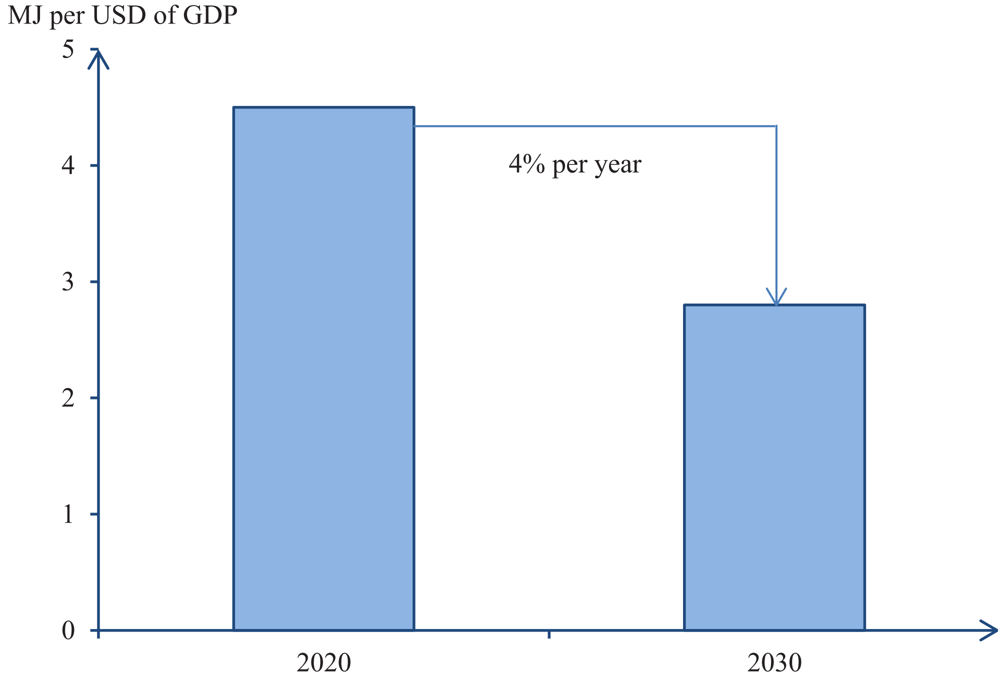

Figure 3 Energy intensity of GDP (MJ per USD ppp). Note: MJ = megajoules; GDP = gross domestic product in purchasing power parity (Net zero, 2021)

in energy systems, thus, are expanding with the development of "green" energy.

Cyberization of system control. The result of Industry 4.0 should be the cyberization of the man-made industrial world.

Based on the analysis of a few publications (Schwab, 2016; Industry 4.0, 2016; Skinner, 2018), the authors formulated the most important functions that the specified cyber-physical systems will have to perform *without human participation:*

– *exchange of information* (a kind of "communication" among themselves) in real time;

– *control of parameters* of the external environment and one's own;

– *self-activation and stopping* at certain informational signals;

– *self-adjustment* to optimal work modes;

– *predicted* (anticipatory, preventive) self-service of systems;

– *interaction with the goods produced by them* (if we are talking about production systems);

– *adaptation to new* consumer needs;

– *determination of the equipment* necessary for the production of necessary goods or meeting new needs;

– *self-learning* new work techniques.

The progress of Industry 4.0 promises to provide a qualitative jump in the efficiency of the functioning of technical systems, including thanks to the development of *the Internet of Things, the sensor revolution, "cloud" technologies, artificial intelligence* and other conquests of technical progress.

One of the important results of Industry 4.0 can manifest itself particularly vividly in the environmental sphere. In particular, the development of cyber-physical systems can become a decisive factor to close the cycles of the use of various types of resources and turn the economy into a circulation system. In *the circular economy,* each product will have its own label, which will show the source of resources, the production technology, the type of energy used, etc. (Dediacoat, 2016).

Sustainable transportation of public institutions. Mankind's mastery of new sources of energy is not just a technological measure. This is a complex socio-economic phenomenon, a phase transition, which means a change in all attributes of a person's social life. Public institutions play an important role in this transition, which determine: the relations of people in society, regulators of the movement of commodity and money flows, the principles of human capital formation, the principles of the implementation of relations between man and the biosphere, and other important aspects of the functioning and development of human society.

Among the most important public institutions, the following should be mentioned: the level of public administration and motivational tools, property rights and economic regulators, legal norms, restrictions and prohibitions, informal norms, customs, traditions, moral norms, religious principles, education, non-governmental organizations, etc.

Only with the active transformation of the entire range of public institutions can we expect to realize the full potential of the updated energy system.

3 Analysis of research results

The transition of economic systems to renewable energy sources largely ensures the fulfillment of the goals of sustainable development. 2/3 of environmental pollution processes are related to energy production. Replacing dirty energy production technologies with "green" ones makes it possible to significantly reduce eco-destructive processes, greenhouse gas emissions, and climate destruction.

The analysis of the research carried out in the work allows us to draw several important conclusions.

1. The introduction of renewable energy technologies is possible only if adequate transformational changes are made in the socio-economic system, the main components of which are shown in Figure 4.

2. The specified socio-economic transformations mutually condition each other and can significantly strengthen the potential impact of the restructuring of the energy complex on the goals of sustainable development, which is also shown in this figure in the form of the "synergistic effect of sustainable transportation of energy".

3. This effect is a multifaceted phenomenon and has many dimensions of its potential. We can formulate several directions for the formation of criteria for their assessment.

Economic dimension. Renewable energy systems require lower public costs for the production of a unit of energy (taking into account the full production cycle) than traditional technologies. In combination with modern energy storage systems, the advantage of alternative technologies grows even more. According to the estimates of the British government, the total cost savings for energy production in the country by 2050 may amount to about 50 billion USD (What, 2022).

Price measurement. Already today, average prices for renewable electricity are lower than electricity produced at thermal power plants (USD / MWh: wind (onshore) – 60; solar (pv) – 63, gas – 75; coal – 130) (Solar, 2020). In the future, the advantage of alternative sources will only grow.

Ecological dimension. Large-scale implementation of renewable energy systems will make it possible to reduce the emission of greenhouse gases (primarily CO_2) by half by 2050.

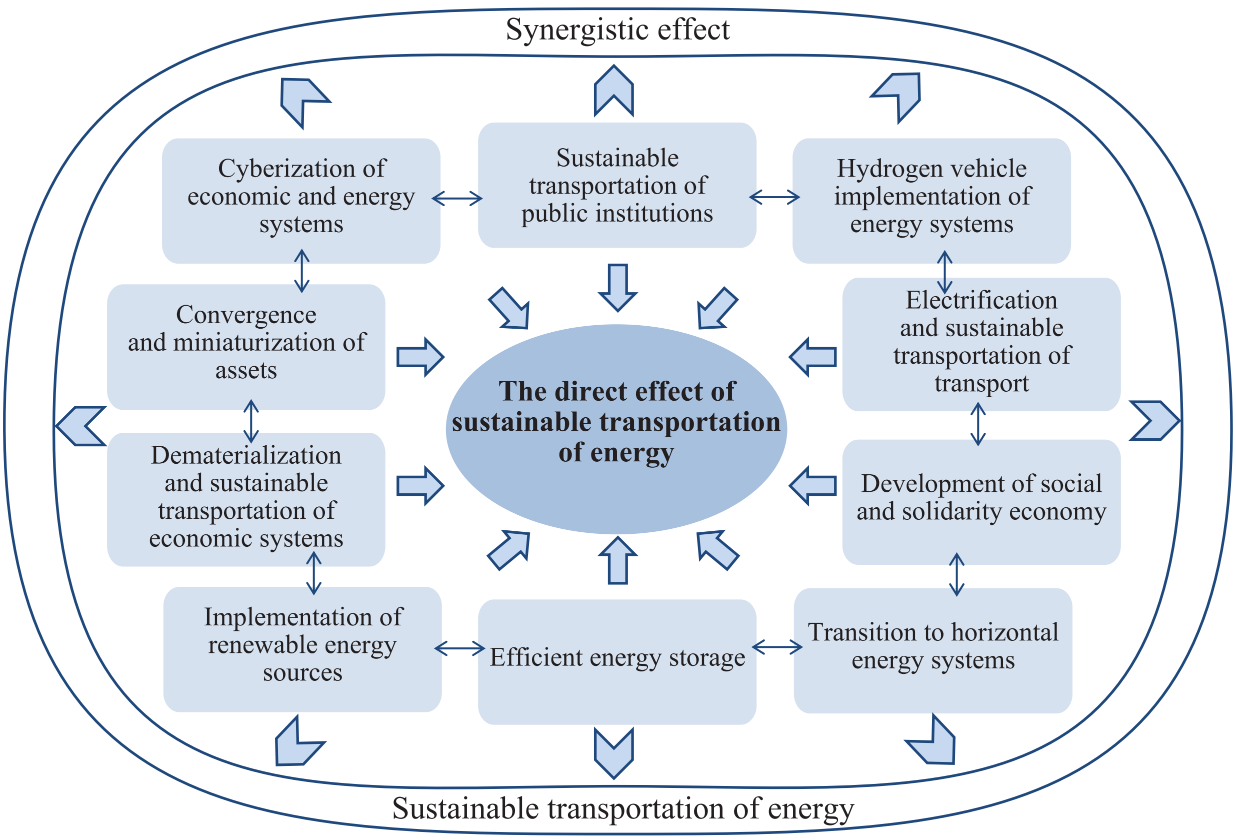

Figure 4 The systemic essence of the synergistic effect of sustainable transportation of the energy sector

It is assumed that by 2050, almost 90% of electricity will be produced from renewable energy sources (wind and solar energy will make up almost 70%). Improvement of ecological living conditions is predicted. A reduction of 2 million deaths from premature deaths is expected (Net Zero, 2021).

Social dimension. Due to the development of renewable energy, by 2030, about 800 million inhabitants of the Earth will have access to electricity and 2.6 billion people will acquire conditions for clean cooking (Net Zero, 2021). Access to energy will significantly increase welfare and labor productivity in developing countries.

Dimension of dematerialization. The transition to alternative energy will make it possible to reduce the specific flows of materials and energy per unit of products (services) in the general industrial metabolism. It is predicted that by 2030, the gross volume of the world economy will increase by 40%. At the same time, energy consumption will decrease by 7%. The annual decrease in energy intensity will be an average of 4%. It is expected that with the maximum implementation of the sustainable potential of renewable energy, global energy consumption in 2050 will be approximately 8% less than in 2020, and it will be able to serve twice the size of the economy and a population of 2 billion more people (Net Zero, 2021).

Restructuring dimension. The transition to new energy sources must be accompanied by a radical restructuring of the economic sectors. This can be illustrated by the flow of jobs from traditional to alternative energy sectors. In particular, the creation of 14 million jobs in clean energy sectors is predicted by 2030. It is also expected that 16 million jobs should appear in various sectors of the economy in connection with cyberization of production, electrification of transport, modernization of buildings, etc. At the same time, 5 million jobs should disappear due to the reduction of traditional energy production (Net Zero, 2021). It is worth noting that the jobs that will be created will have more intelligent and ecologically perfect working conditions than those that will disappear.

4. The transition to renewable energy systems requires constant innovation. Approximately one-third of the technical means, which are supposed to implement the task of transition, do not yet exist on the market and are being developed in scientific developments.

5. The tasks of the mentioned energy transition require adequate institutional support and international cooperation. Without such support, the goal of realizing the full potential of the energy transition and the corresponding goals of sustainable development can only be achieved, relatively speaking, by half (Net Zero, 2021).

4 Conclusions

The production and consumption of energy is the main area where most of the eco-destructive processes of human influence on the ecosystems of the planet are formed. Accordingly, it is here that most of the measures to achieve the goals of sustainable development can be implemented. The key direction of the environmentally oriented reform of the energy sector is the transition to renewable sources and efficient energy storage.

An integral part of this transition is the transformation of the entire deep essence of the socio-economic system, which in one way or another conditions the processes of energy production and consumption. The main components of this transformation are transition to horizontal distributed energy networks, development of social and solidarity economy, dematerialization and sustainable transportation of economic systems, convergence and miniaturization of assets, electrification of transport, modernization of energy systems, cyberization of control over the work of systems, sustainable transportation of public institutions.

By mutually determining each other, these transformative components form the synergistic potential of the efficiency of renewable energy and the prerequisites for the sustainable development of society.

The mentioned energy transition is a dynamic technological and socio-economic phenomenon, the driving force of which is innovation, which must be constantly reproduced by systems of fundamental and applied sciences.

The full potential of achieving the goals of sustainable development in the course of the specified energy potential can be realized only under the condition of adequate institutional support and active international cooperation.

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