“Additive economy and new horizons of innovative business development”

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ADDITIVE ECONOMY AND NEW HORIZONS OF INNOVATIVE BUSINESS DEVELOPMENT

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Abstract

The disruptive technologies and cyber-physical production systems are important factors that bring transformations to socio-economic formations. The paper aims to formulate the content, key directions, positive and negative effects of additive economy (AE) in the current transition phase to Industry 4.0. The research method is based on the analysis of structural links in socio-economic systems, where the additive economy potential is realized. The additive economy is treated as a new approach to production technological aspect based on the additive principle of manufacturing and aimed at minimizing the use of primary natural resources for dematerialization of social production. AE is the antithesis of the subtractive economy, which dominates today and uses only a tiny proportion of extracted natural resources. Among the positive effects of AE, there are the reduction in energy intensity of products, dematerialization of production, solidarity of society, economic systems sustainability, and intellectualization of technologies and materials. Among the negative expectations of AE, there are increased information vulnerability of production, risk of losing control over cyber-physical systems, expanding the unification of individuals, and increasing psychological stress. The additive economy is more sustainable than the subtractive economy since it does not require extra components to the production spheres, reduces the resource scarcity, and could satisfy more economic agents' needs. Therefore, improved production efficiency due to AE promises economic growth acceleration, environmental burden and social risk reduction.

Keywords economic growth, 3D-printing, disruptive technology, production, sustainable development, dematerialization, intellectualization

JEL Classification M11, O14, O30, O40

INTRODUCTION

Productive forces are the basis of any socio-economic formation, which determine the impact of economic systems on the environment and key parameters of social development, and form the economic relations in society. Humanity is experiencing a phase transition to a new socio-economic formation, which promises to change the technological basis of production and social relations. The bulk of scientific works have studied the features and characteristics of social change due to Industries 3.0, 4.0, and 5.0. In particular, the changes that Industry 3.0 brings to society are analyzed by Rifkin (2013) and Shahan (2020); Industry 4.0 is discussed by Schwab (2017), Skinner (2018), and Taleb (2012); Industry 5.0 potential is shown by Maddikunta et al. (2022).

The transition of production systems to alternative energy (Kurbatova & Sidortsov, 2022; Trypolska et al., 2022) and additive technologies for processing material resources (3D printing) is a leading trend today. The features of additive production methods

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are discussed in detail by Barnatt (2016), SPI Lasers (2017), AM (2016), Berman (2012), Quanjin et al. (2020), Reddy (2022), and Sculpteo (2021). However, the additive economy (AE) concept should be considered much more broadly and has not to be limited to a method of product manufacturing.

1. THEORETICAL BACKGROUND

The term "additive" in research is usually associated with "technology" and is considered a certain antithesis to traditional (subtractive) production technologies. The subtractive technologies are based on using a relatively small part of the resources extracted from nature, returning the rest to natural ecosystems as waste in a much more toxic and harmful form. According to Melnyk (2014) and Sineviciene et al. (2021), the share of the valuable substance in subtractive production does not exceed an average of 10 percent, which means that the remaining 90 percent of raw materials are returned to nature, polluting and destroying its ecosystems.

Additive manufacturing is built on the principle of additivity, i.e., using only the necessary components (energy and substances) extracted from nature. Renewable energy produces the energy needed, and 3D printing produces material things with minimal natural resources. Thus, traditional energy relates to fossil fuel resources and burns only their energy-intensive element (carbon), leaving the rest in the form of waste (Karintseva et al., 2021). Additive manufacturing or additive layer manufacturing refers to technologies that create (build) three-dimensional objects from a 3D computer model by depositing (adding) layer by layer of materials: plastic, metal, concrete, or cells of biological organisms (SPI Lasers, 2017; AM, 2016).

Additive manufacturing combines production methods based on the gradual molding of products by adding material to the base (platform or workpiece) on a three-dimensional computer model. The following methods are often used: selective laser melting, laser stereolithography, selective laser sintering, electron beam melting, lamination effects, and computer axial lithography. The areas of additive manufacturing application are almost all sectors of the economy, in particular construction, agriculture, engineering, shipbuilding, aircraft, aerospace, medicine, and pharmacology.

In addition to the savings in raw material costs, additive manufacturing significantly reduces the technological costs for preparing production processes (labor, energy, and materials).

Additive manufacturing, according to Yeh (2014) and Mohajeri et al. (2016), allows realizing the significant benefits, in particular, unlimited design possibilities; free complexity; free provision of variability; minimum waste; production according to the requirements of the individual customer; the ability to make changes at the last moment; exclusion of the harvesting stage; direct materialization of information images. The following materials are used in additive technologies: wax, gypsum powder, liquid photopolymers, metal powders, various polyamides, and polystyrene.

There are four main classes of 3D printers: industrial, design, professional, and home printers. Industrial printers used in large industrial facilities are characterized by high accuracy. They can work with various industrial materials (particularly high-strength and heat-resistant). Design units are used in design activities, mainly to visualize design ideas and, in some cases, to manufacture and test prototypes of future products. Professional printers are relatively reliable and solve various production, research, and business problems. Unlike personal (home) computers, they are characterized by high accuracy, stability, and repeatability of printing; their work term is 7-10 years (for comparison: at home – up to a year). Home printers are characterized by low-quality and low stability of construction. They are used in everyday life and schools to manufacturing various inexpensive items.

Today, scientific research predicts the economic systems' changes in connection with the transition to an additive economy (Table 1).

In 2021 global sales of 3D printers and materials, software, and services for this equipment approached 16 billion euros. The forecast for 2025 is almost 42 billion euros, and for 2029 – 103 bil-

Table 1. Projected effects of additive economy development until 2025

Source: Compiled based on Schwab (2017), Schwab and Davis (2018), Manyika et al. (2013), Skinner (2018).

Technology	Potential effect assessment
3D printing	It can save from 35 to 60 percent of operating costs per unit of manufactured products and achieve a very high level of customization (i.e., manufacturing according to individual customer requirements). Five percent of consumer products are 3D printed. For example, the first liver transplant was created using 3D printing technology.
Mobile internet	10-20percent reduction in the cost of treating chronic diseases through remote health monitoring.
Internet of things	It will reduce operating costs to 36 trillion US dollars due to increased efficiency in processing, healthcare, and mining; 1.2-3.7 trillion US dollars of economic effect; Economic effect 0.4-1.2 trillion US dollars due to self-service, intelligent contact producer with consumer.
Blockchain	10 percent of global GDT is saved thanks to blockchain.
Sharing economy	More than 50 percent of the number of trips by car sharing.
"Cloud"	15-20 percent increase in productivity due to the creation of IT infrastructure and the development of necessary applications and programs; Economic effect from 1 to 6 trillion USD per year due to cloud technologies.
Advanced robotics	Potential to improve the lives of 50 million amputees and those with impaired mobility.
Energy saving	40 to 100 percent of vehicles are expected to be electric or hybrid.
Advanced materials	The use of new nanomedical drugs can successfully cure up to 20 million newly diagnosed cancer cases.
Renewable energy sources	It is possible to prevent CO_2 emissions from 1 to 2 million tons until 2025.

lion euros (IDEA Consult, 2021). Furthermore, the French company Sculpteo analyzed global 3D printing in 2021, and more than 1,900 users of 3D printers from 86 countries were interviewed (Sculpteo, 2021).

Therefore, this paper aims to reveal the essence of the additive economy as a system phenomenon and determine the transformational vectors of its forming, positive and negative effects in the current phase of transition.

2. RESULTS

In general, the economy is a sphere of economic activity related to producing, using, and managing scarce resources. In contrast to subtractive technology, the additive production methods do not cut off the wastes but add the necessary components. This is how 3D printers work, adding substance layer by layer, thus materializing the informational images of the goods produced. However, the concept of "additive" might be much broader than just the production method. It may include the transition of the economic system to new productive principles. Behind the subtractive techniques, there is a holistic system of adequate processes – from the receipt of primary raw materials to the consumption of final products and disposal of residual waste. The transition to additive methods means a phase transition to a new socio-economic formation, which can be called an additive economy. It must mean a leap of society to a new level of efficiency of social production.

As with any complex phenomenon, the economy can be characterized in many ways according to its facets. In particular, when the critical objects of realization of economic processes are put in the first place, then one may speak about the economy of the enterprise, region, and country. Considering the leading form of regulation of economic processes, one may speak about the market or planned economy. The paper proposes a fundamentally new approach to classifying the economy as a system, where the principle of natural resources processing is put forward. For the first time in the history of civilization, humanity is radically changing the technological principles of processing natural resources, moving from the dominance of subtractive technologies to the large-scale application of additive technologies.

Subtractive technologies have come a long way in improving and increasing efficiency. The key milestones on this path were the following stages:

- *extensive mode of resources use* (founded on the scaling of basic technologies and involvement of new amounts of natural factors into economic processes);

- *intensive mode operation of resources use* (founded on increasing the efficiency of using a unit of natural resources through the use of industrial technologies in the processing of resources);
- *innovative mode operation of resources use* (founded on increasing the efficiency of using a unit of natural resources through information technology in the control of production processes).

At the current stage of human development, subtractive principles of cooperation between humans and nature have exhausted their opportunities. The transition to an additive economy with its production basis means ascent to a new degree of increasing the social efficiency of natural resource usage.

The AE may be defined as a socio-economic formation based on the widespread use of the additive manufacturing principle (3D printing) aimed at radically minimizing the use of primary natural resources and dematerializing social production. The efforts of human civilization, which are often spent on the extraction and processing of resources, can be aimed at the personal development of humanity.

The phase transition to the additive economy is a complex social process; the systemic components are separate areas of the socio-economic system. Transformational processes of formation of the main of them are shown in Figure 1. Each of these transformation processes is a bifurcation change that allows many possible ways of its development and has to be discussed separately.

Product convergence involves combining several properties and functions into one object or device to further use this device for different purposes. Kranz et al. (2021) define convergence technologies as a term that means a combination of technologies (often in one device) that were previously used separately from each other (as a term that describes bringing previously unrelated technologies together, often in a single device). Thus, *convergence* is usually understood as multifunctionality. A striking example of convergence is a modern mobile phone. It contains everything that was a separate, rather voluminous subject a few years ago: a computer, a telephone, a camera, a video camera, a flashlight, a notebook, an alarm clock, a calendar, and much more. However, this list should also include features that have never existed before, such as "e-mail operator" or "personal memory unit."

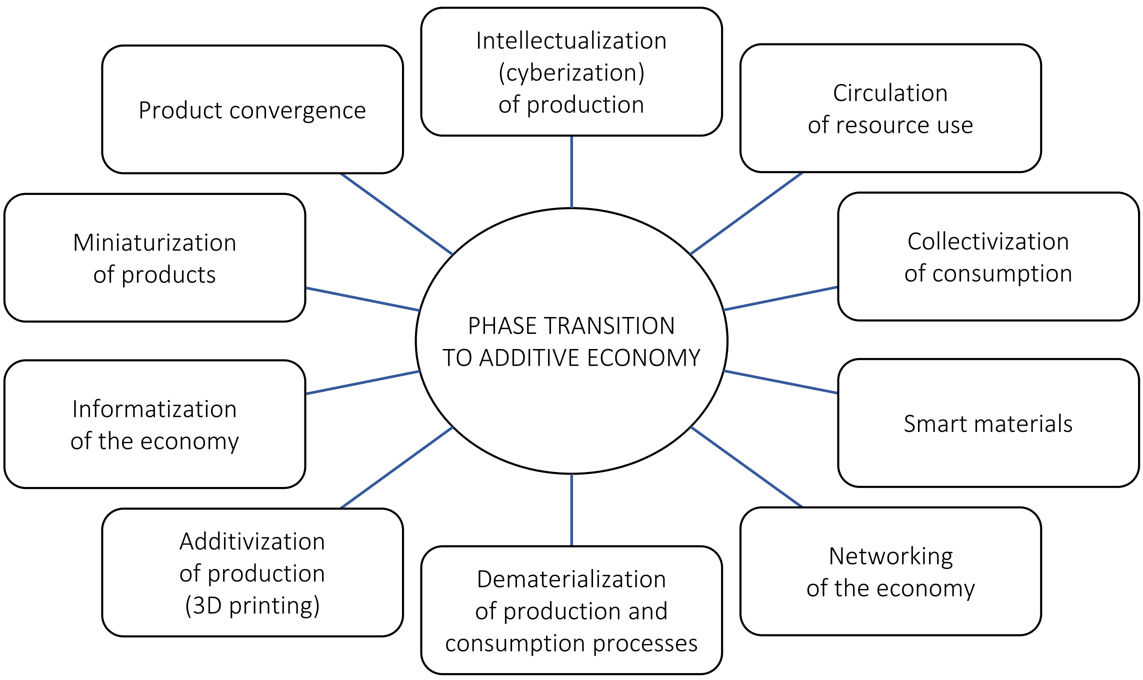

Figure 1. Components of transformations of phase transition to the additive economy

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Miniaturization can reduce the size, mass, and energy consumption of devices, mechanisms, machines, and others. While improving their quality characteristics, reliability, and degree of automation of design and production processes, miniaturization is based on blocks and knots from miniature elements and an increase in the density of their complete set.

Dematerialization is a phenomenon of material elements reduction (energy and substances) in the composition of technologies, finished products, and supply processes (transportation and storage) due to the increase in the economic cycle of the information component. The informatization of transportation and storage of products provides significant savings in materials and energy (Sotnyk, 2012). Today, instead of transporting material products, their information images are increasingly being transmitted as "digital duplicates," which the recipient materializes with the help of 3D printers. The same can be said about product storage processes. Storing not the products themselves but their digital counterparts saves many materials and energy and prevents losing their quality properties.

Smart materials are a purposeful change in the properties of materials (especially their quality characteristics and functional orientation), which can significantly increase the efficiency of economic systems where these materials are used. Smart materials are a highly effective way to reduce the resource intensity of the entire economic system. In particular, it makes it possible to significantly reduce the energy and material consumption of production systems in three stages: production of raw materials, the manufacture of the material, and its use in technical systems. In addition, new materials with their incomparably higher functional properties can replace several expensive and resource-intensive (in their production) materials; they usually also significantly reduce the resource-intensive functions. However, the effects of resource conservation from using new materials are not limited. Usually, there is also an effect due to their production's significantly lower material consumption and energy consumption than the materials they replace. Smart materials open the way to 4D printing, which is based on the ability of materials to change their properties (e.g., shape) after the end of the technological operation on a 3D printer. There is a fourth dimension, when the product acquires its final shape and other properties. "Smart" materials can "turn on" their "memory" at any time, even at long intervals after their publication. Factors that "turn on" the "memory" of materials can be different parameters of the environment to which the materials can respond. 4D printing can be used in many areas of the economy, including space, automotive, transport, utilities, emergencies, aircraft, medicine, robotics, electronics, and art.

Circulation of resource use is the transition to renewable resources in closed cycles. The end of using a resource in one of the cycles of production and consumption means the beginning of its use in another process. Circulation of resource use lays the foundation for building a circular economy, or closed-loop economy, i.e., a holistic system of production and consumption of products based on circulating resource use. Prerequisites for the development of circulating resource use are created during Industry 4.0 and the formation of the Internet of Things. Bauwens et al. (2020) gave their original definition of the circular economy. In this definition, the authors find a place for circular resource use: "The circular economy is a model of production and consumption in which existing materials and products are shared, leased, reused, repaired, refurbished, and recycled for as long as possible. In this way, the product life cycle is extended."

Informatization of the economy can be conditionally called replacement in production assets and consumption of their material part of the information component. Information is increasingly beginning to perform the functions of those key economic system components that previously served as tangible assets (Sotnyk, 2012; Sotnyk et al., 2013). Among them are raw materials (e.g., primary information); means of work (computer program, technical process, management decision); subject of work (information in processing and analysis); finished products (trained specialist and scientific innovation); means of consumption (artwork, news, and tourism); capital (source of income) (patent and brand); goods (object of sale: information service, and patent); property (copyright); and security tools (antivirus program, code,

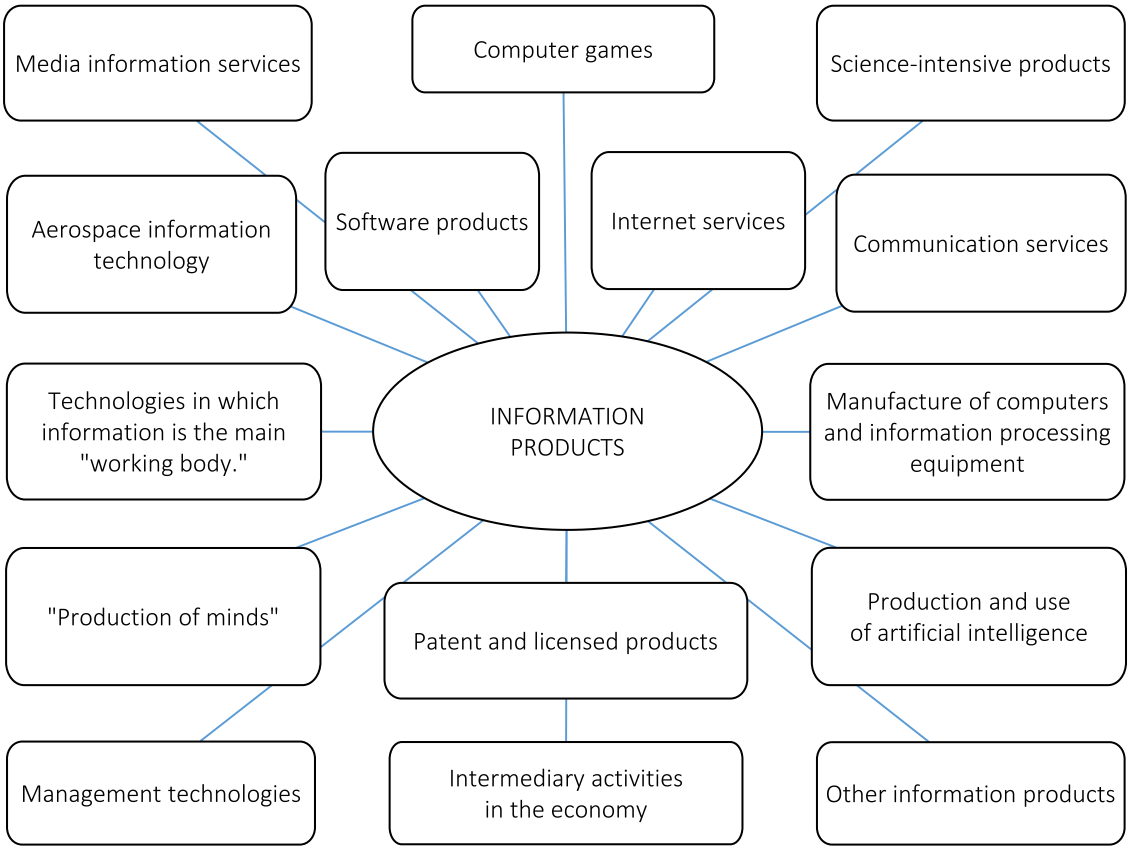

Figure 2. Some types of modern information products

and password). Moreover, the importance of information forms in the economic system will continue to grow steadily. Consumer goods are becoming more and more digital. However, in many modern goods and services, their material component is only a carrier of information (Figure 2).

The most significant transformation promises to take place within humans themselves. In the triad of its components, "bio-labor-socio," the leading position should be occupied by the personal (informational) essence of man, i.e., man "socio." This means that man's unique characteristics will determine the development of the production environment and the formation of the contours of society.

Networking of the economy should be understood as an organizational transformation of economic cycles under which extensive production facilities concentrated in the territory (enterprises, plants, and associations) are replaced by horizontally distributed networks that combine the activities of small production units. An example of a horizontal production network is the EnerNet system developed in Europe, which aims to combine alternative energy sources (solar panels and wind turbines) in European countries. Such networks perform a set of highly complex technical and economic functions, particularly *air conditioning* (bringing to standard parameters); *transmission, storage, conversion, and* energy use in the most efficient modes; ensuring *the stability* of energy systems. In addition, the most complex economic problems of buying and selling energy with its multifactor tariffing are solved. Similar network forms of production organization can be used to process materials. The fact that additive production can exist without a number of intermediate production stages (preparation of materials, manufacture of equipment, processing of materials, assembly of finished products, etc.) eliminates the need to concentrate on a particular area of production capacity. Therefore, production and consumer networks come, where producers and consumers can be significantly separated in space, sometimes on different continents. This may be because production will be reduced to digital duplicates, which will materialize through

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3D printing directly by consumers or production units that serve them.

Intellectualization of production is endowing production systems with self-reproduction (replication), self-learning, and self-improvement. The basis of the intellectualization of production is artificial intelligence and cyber-physical systems. Therefore, this transformational transition can also be called cyberization. For example, copying was carried out by 3D printing through the sequential application of thin layers of molten polymer. The RepRap (Replicating Rapid-prototyper) robot has been optimized so that its parts can be printed on it. An organic continuation of these studies today is the development of so-called cognitive technologies. They are based on programs that have the ability to self-write and self-improvement. The ability of technical systems to self-organize and self-improve plays a vital role in ensuring their stability and steadily improving the efficiency of functioning, particularly the rational use of resources.

Collectivization of consumption is the transition to an economic model that involves the collective use of goods based on the lease of goods or the purchase of services instead of goods. Under this model, consumer goods retain the property of the producer. The consumer can use the service through a lease or rental agreement. Sharing schemes for bicycles, scooters, and even cars are now used in many European countries. The sharing models of the economy are favorable conditions for rational resource use. First, the manufacturer increases the incentives to create durable products to prolong its life cycle. Secondly, leaving the entire life cycle of products in their hands, the manufacturer can organize recyclable structures of goods and build appropriate schemes for recycling resources. Today, tractors, pumps, compressors, and other equipment are switching to similar models. Citroen has introduced a small and inexpensive electric car Ami One, which does not plan to sell. The vehicle will be available only for sharing forms. Even Ikea has announced that it is moving to a furniture leasing business model.

Positive and negative directions of additive economy development. Additive economy means the leap of humanity to a new qualitative level of its development. However, it is naive to assume that these achievements of humanity and any complex phenomena have only positive effects, which are not overshadowed by negative consequences. Therefore, system analysis is valuable only if it allows for tracing its negative side along with the positive components. A systematic view of the development of the additive economy is presented in Table 2.

Table 2. "Horizons" (expected socio-economic effects) of the additive economy

Expectations	
Positive	**Negative**
• Energy basis (transition to alternative sources) • Material basis (3D-printing and dematerialization) • Environmental impact (sustainable technologies) • An economic system (networking of production and consumption) • Technological basis (intellectualization and artificial intelligence) • Humanitarian framework (individual health control) • Social life (solidarity of society)	• Information systems (vulnerability to accidents, viruses, hacker attacks, power supply) • Technological basis (risk of losing control over cyber-physical systems) • Humanitarian basis (human dependence on artificial intelligence) • Psychological basis (risk of psychological disorders) • Personal effects (transparency of private life) • Socio-conformational effects (risk of total unification) • Society (risk of degradation)

A fundamental feature of the current stage of development is the transfer of the center of gravity in the production process from the cycle of product replication to the cycle of its design. This is where the primary value of the future product is laid, i.e., its information characteristics: properties, functions, and operational parameters (reliability, aesthetics, etc.). In other words, the role of production capacity will be reduced to those functions performed by a conventional printer, which is turned on at the touch of a button when we need to print a stack of printed materials. Horizontal distributed networks have significant advantages over modern spatially concentrated industries. They are much less material-intensive, modular (allow network expansion due to new units), provide direct contact between producer and consumer, and create conditions for personalization of products, i.e., its production taking into account the wishes of specific consumers.

3. DISCUSSION

Humanity is currently experiencing a transition to a new socio-economic formation. Its production basis is a recent social phenomenon, conditionally called additive economy. However, it should be noted that the additive economy has only just appeared on the "horizon" of human social development. Most of it is beyond the "horizon" of the views of scientists and experts. Every step in technological and social progress brings societies closer to a new socio-economic formation and opens the next horizon.

Further studies would look beyond the horizon to predict the consequences of scientific and technological progress, strengthen additive economy positive effects, and avert or reduce negative expectations' impact (risks). The formation of AE means the transition of humanity to new principles of nature management, which will radically minimize the ecological burden of civilization on the ecosystems of the planet (Veklych et al., 2020). AE promises to change the essential components of human society – from its technological basis to the content and forms of consumption. What gives the formation of the additive economy (AE) in terms of the impact on the scarcity of resources in the implementation of the economic process? By reducing the energy, material intensity of production, consumption, and distribution, the AE reduces the scarcity of resources. In other words, the production and consumption of more material and information goods can be ensured within the available resources. The AE pushes the boundaries of the mentioned resource constraints. The ability of AE to influence the resources scarcity causes several consequences that are extremely important for the development of civilization. Firstly, AE increases the creative potential of humanity within existing resource scarcity. Secondly, the specific amount of natural materials required to satisfy a conventional unit of social needs decreases, reducing the environmental pressure on ecosystems ("ecological footprint"). Thirdly, the amount of waste objectively caused by production is significantly reduced; this promotes to increase in the carrying capacity of natural systems; in other words, the conditional capacity of the assimilation potential of the planet increases. Fourthly, prerequisites are being created to achieve sustainable development goals since meeting the needs of living generations is less contrary to meeting the needs of future generations. Fifthly, the informatization of economic processes determines the dominant development of the information essence of a human, i.e., his/her personality, which is the important goal of humanity's sustainable development.

The attention of experts to the evolution of socio-economic systems and predictive assessments of the state of their components makes it possible to get an idea of the contours of the key changes that bring to humanity the development of the additive economy. Furthermore, disruptive technologies bring sustainability both to the agricultural (Klymchuk et al., 2020) and financial spheres (Benetyte et al., 2021).

Assessing the possible consequences of introducing breakthrough technologies is of great importance. This allows comparing the costs of their development and development with the effects they can bring. Justifying the most effective investments in innovative projects plays a significant role against the costs invested in implementing breakthrough technologies (Melnyk et al., 2013; Koblianska & Kalachevska, 2019).

The positive impact of the additive economy is reduced to the sustainable energy production technologies and dematerialization, creating conditions for progressive social (personal) human development. Increasing information complexity and cyborgization of technological systems make it possible to increase their efficiency significantly. At the same time, their exposure to technical failures (accidents, power outages, damage to communications, etc.) and unauthorized information influences (computer viruses and hacker attacks) significantly increases. In reality, these negative situations can nullify ("reset") many of the possible positive effects.

The enormous complexity of cyber systems that manage technological processes leaves people with less and less control over their activities. This risk is exacerbated by the ever-increasing ability of cyber-physical systems to self-design and self-organize. Another factor that may increase the risk is the growing role of the Cloud in the management of economic processes. Currently, this su-

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per information system operates in global memory mode. However, it is rapidly evolving toward forming a system of universal meta-minds capable of controlling the existence of civilization.

The constant concentration on the perception of information, in combination with a decrease in physical activity, can cause specific forms of addiction, similar to the effects of drugs. The consequences can be mental health problems and bad behavior in society. Information control over technological systems of highly high complexity requires substantial psychological stress for man, which not everyone can withstand. The situation is complicated because such information loads are not genetically inherent in man, and he has to learn digital skills again. The psychological load is exacerbated by the acceleration of transformation processes and constant changes in working conditions. Digital technologies make a person almost transparent to society. On the one hand, it helps prevent various illegal actions. On the other hand, it makes a person vulnerable to negative social influences and criminal acts of an informational nature.

Hence, the future study aims to design business models of additive economy implementation in the direction of phase transition to Industry 4.0, accounting for sustainability fostering and mitigation of social risks related to digital technologies implementation.

To achieve the future goal, it is proposed to use such an approach. Firstly, it is planned to conduct interviews with businesses implementing additive economy in their operational activity. Secondly, based on the interview results, there is a need to formulate an expert generalization to strengthen the additive economy's positive effects and reduce the impact of its negative expectations.

CONCLUSION

In summary, many factors continually drive the development of the additive economy. However, there are still many uncertainties, especially regarding the formulation of the content, key directions, and positive and negative effects of the additive economy in the current phase of transition to Industry 4.0.

The literature review pointed out that an additive economy is a socio-economic formation based on the widespread use of the additive manufacturing principle (3D printing) to radically minimize primary natural resources and dematerialize social production.

The phase transition to the additive economy means a systemic phenomenon, the transformational components of which should be: additivity production, networking of the economy, convergence and miniaturization of products, informatization of the economy, smart materials, intellectualization (cyberization) of production, collectivization of consumption, and circulation of resources.

The results of the study reveal that the development of the additive economy brings both positive and negative effects that can be expected in society. Among the positive effects are a significant reduction in energy intensity of products, dematerialization of production, solidarity of society, economic systems sustainability, intellectualization of technologies and materials, and individual health control. On the other hand, among the negative expectations, there are increased information vulnerability of production, risk of losing control over cyber-physical systems, expanding the unification of individuals, increasing psychological stress, and others.

The additive economy is different from the traditional one since it aims not only to optimize the use of scarce resources but also to minimize industrial waste during production processes. The additive economy reduces resource scarcity and could satisfy more economic agents' needs. Moreover, an additive economy is more sustainable than a traditional one since it does not require extra components for the production spheres. The problem with the additive economy is related to determining the maximal approvable level of waste within the industrial processes.

AUTHOR CONTRIBUTIONS

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Project administration: Oleksandr Kubatko.
Resources: Oleksandr Matsenko, Maxim Korneyev, Oleg Tulyakov.
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Supervision: Leonid Melnyk.
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