ISSN: 2723-9535

Available online at www.HighTechJournal.org

HighTech and Innovation Journal

Vol. 6, No. 1, March, 2025

Quasi-Viral Technologies as the Drivers of the Economy Digital Transformation Towards Sustainability

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Received 17 October 2024; Revised 15 February 2025; Accepted 21 February 2025; Published 01 March 2025

Abstract

The relevance of the article is related to the phenomenon of quasi-viral technologies, which are the drivers of the phase transition to sustainable development. The study is aimed at defining the category "quasi-viral emerging technology", as well as the disclosure of their content and form, and the analysis of the features in the conditions of digital transformations. The research method is based on the analysis of transformational changes in the components of the trialectic mechanism of the reproduction of socio-economic systems, which occur under the influence of quasi-viral sustainable technologies. The article defines the quasi-viral process of spreading emerging technologies as a transformational process of the informational component replacement within the technological base by methods imitating the course of viral infection. The signs of quasi-viral processes are formulated on several levels: "infection" due to a change in the information algorithm; substantial user preferences; lack of sufficient barriers; significant potential to increase users; and disruptive efficiency. Signs of quasi-viral technologies have the following types of innovations: renewable energy, 3D printing, electric transport, energy storage, IT technologies, digital recording of information, cloud technologies, etc. The authors hypothesize the possibility of using entropy estimates as the only measure of approximating the results of the implementation of quasi-viral technologies to the state of sustainability in society and nature. The expected results of the spread of quasi-viral technologies can be significant dematerialization of industrial metabolism, provision of functions of self-organization and self-improvement of social systems, preservation of biodiversity and ecosystems of the planet, and formation of the foundations of sustainable development.

Keywords: Quasi-Viral; Sustainable Technology; Digital Transformation; Driver; Transition; Digital Economy; Information Algorithm.

1. Introduction

The new wave of technical rivalry and the global industrial revolution give green technological innovation more importance because of the environment's degradation. Green technology innovation encompasses the development of new products, services, and management approaches [1]. It is a key component in achieving sustainable development and is a sign of productivity, sustainability, and a decrease in negative effects on the manufacturing process [2, 3]. There

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http://dx.doi.org/10.28991/HIJ-2025-06-01-013

are not legally mandated outdoor (ambient) air quality regulations in one-third of the world's countries. When such regulations are in place, the requirements are frequently out of step with the recommendations of the World Health Organization (WHO). Furthermore, among the nations that do have the authority to enact ambient air quality guidelines, at least 31% have not done so yet. These are some of the main conclusions of the UN Environment Programme's (UNEP) first-ever evaluation of air quality laws and regulations. There is an increasing emphasis on how environmental regulation may meet the ecological concerns, since manufacturing and industrial processes account for one-quarter of Greenhouse gases (GHGs) emissions [4]. In addition to academic research, regional and international organizations like the UN, G7, and BRICS have worked to reach an environmental agreement to support the preservation of ecological sustainability [5].

People are more concerned about local events that affect the short-term future and pay less attention to events on a larger scale. Local events can be considered separately from events at a larger spatial time scale. One of the most striking illustrations of the above is climate change, the consequences of which already started to affect the lives of millions of people globally. The climate change processes around the world resemble the entropy dissemination processes in physics, which were opened more than one century ago. Entropy characterizes the probability that the macroscopic state of the system will be realized and pointed to the fact that in nature, the processes of irreversible dissipation of energy are more probable than the opposite processes of energy concentration. This is very close to another concept of entropy as a measure of chaos or disorder. For that reason, the entropic concept could be used in environmental economics to estimate the efficiency of economic processes with respect to physical and biological laws [6]. The paper provides the environmental analysis of socio-natural processes and estimates the "entropic value" of economic activity. On this scientific basis, one of the most important principles of sustainable development can be implemented: “Think globally—act locally”. Digital local finances have the potential to expedite loan applications, reduce credit assessment costs, and create new funding streams for business innovation [7]. It reduces the financial services threshold, broadens the scope of financial services, and aids in fostering corporate technological innovation [8]. Conversely, green technology innovation can help companies achieve their sustainability development goals, increase their competitiveness, and open new markets.

According to Brawn and Wield, green technology innovation refers to production and manufacturing techniques that can reduce the use of resources like energy and raw materials as well as pollution of the environment [9]. The transfer of corporate green knowledge into environmental performance is facilitated by the application of green technological innovation [10]. It increases productivity and lessens the degradation of the environment [11]. Most of the literature now in publication on green technology innovation also discusses environmental regulation. Zhu et al. came to the conclusion that sensible environmental laws would support the development of green technologies [12]. On the basis of Porter's thesis, several researchers have verified that environmental regulations can stimulate the development of green technology [13–16]. However, Lin et al. [17] came to the conclusion that environmental legislation impeded the advancement of green technologies. They said that companies that pollute a lot have to pay more to comply with restrictions. Environmental policy and green technology innovation are shifting in a U-shaped way, according to Behera et al. [13]. Numerous academics also investigate green technology innovation from various angles. Green finance has the potential to boost corporate green technology innovation, according to Na et al. [18]. Furthermore, the advancement of green innovation depends on economic growth [19]. Furthermore, government subsidies significantly increase industrial firms' incentives to explore green innovation [20]. Pedro et al. provided evidence that businesses could increase the intensity of their R&D investment to foster green innovation activities [21]. Zhao et al. investigated the relationship between green innovation and board size. The results show that increasing the number of board members can facilitate the adoption of a green innovation strategy and increase the scope and transparency of innovation [22]. Furthermore, the expanded producer responsibility program has greatly aided in the advancement of green technology innovation [23]. Moreover, carbon dioxide emissions can be reduced with the use of green technology innovation [24–26].

Currently, humanity is undergoing a transformative phase towards a new socio-economic formation, which should provide the prerequisites for the sustainable development of civilization. This transition co-occurs in the conditions of three interconnected industrial revolutions: Industries 3.0, 4.0, and 5.0. Each revolution possesses distinct contextual conditions for the occurrence and development of events. Together, they form the systemic essence of the mechanisms and factors of a profound change in the principles of human civilization's existence on Earth and its relationships with the planet's biosphere. Primarily, this entails achieving a sustainable equilibrium between nature and society.

The critical task that solves the implementation of Industry 3.0 is solving the problems of the global environmental crisis and achieving such development through the transition from subtractive to additive principles of the functioning of socio-economic systems. Additive technologies are characterized by their ability to extract only the necessary resources from nature while minimizing waste generation. The primary objective of Industry 4.0 is to ensure the functioning of additive manufacturing with extremely high information complexity. To achieve this, a widespread adoption of cyber-physical systems within the production process is necessary. On the other hand, Industry 5.0 focuses on advancing societal development through a synergetic combination of the unique personal characteristics and cognitive potential of cyber-physical systems and artificial intelligence.

A characteristic feature of the phase transition process is the quasi-viral nature of new disruptive technologies spread, unprecedented in terms of content and form. It requires fundamentally new approaches to the management in space and time of the corresponding processes of implementing the mentioned industrial revolutions. This determines the relevance to study the fundamentally new content and form of the essence of socio-economic phenomena.

However, the extant scientific literature lacks a comprehensive study of fundamentally new economic systems that resemble the quasi-viral nature of the spread of sustainable innovations during the current phase transition to a new socio-economic formation. Addressing this gap is precisely the objective set by the authors of the article. This research is relevant as it addresses the imperative of establishing fundamentally new mechanisms to effectively manage the processes of creating prerequisites for innovation emergence, facilitating their widespread adoption, and adapting social institutions accordingly.

2. Theoretical Background

Disruptive technological innovations are the key driving force of socio-economic transition and could be viewed as an intensification of anti-entropic activity. Disruptive technologies fundamentally change the character of the productive forces, which naturally causes the transformation of social institutions. The anti-entropic potential of the Earth functions in a similar way as any multistage reactor. Its efficiency depends on the efficiency of each of the stages and the functioning of the inter-stage transitions (transmissions, transactions).

According to one definition, entropy is a measure of disorder in a system. It can also be interpreted as a measure of the lack of information to bring it to the maximum possible order [27]. In other words, the higher the entropy, the greater the disorder. Another definition relates entropy to the decrease in the ability of a system's energy to do work [28]. The research by Melnyk [6] considered these concepts in more detail. Thus, entropy brings us closer to interpreting system-formation processes through the trialectic mechanism of its reproduction in the interaction processes of three groups of system-forming factors: material, informational, and synergetic. A decrease in entropy in the system increases the creative potential of the specified trialectic mechanism and vice versa: an increase in entropy leads to a deterioration in the functional activity of the identified factors and the entire system. The above is true for any type of system, including environmental and economic ones. Entropy is one of the fundamental concepts that characterize natural processes. It was first introduced in the framework of thermodynamics to describe the state of a thermodynamic system and to quantify the irreversible energy dissipation [29–31]. This is, in particular, formalized by a Clausius statement: “heat cannot spontaneously pass from a less heated body to a warmer one”. In a closed system, entropy tends to evolve to a maximum, and the system itself tends to move towards its equilibrium. After all, the closer the system is to the thermodynamic equilibrium, the smaller the difference in energy potentials between the parts of the system, and the less it is able to cause any type of motion and perform work, which ultimately is the criterion for the ordering of the system. One of the prerequisites for the order of the system is a potential difference between parts of the system or between the system and the external environment. The connection between entropy and information is not accidental. Entropy is a measure of the disorder in a system. This can be interpreted as a measure of the lack of information on ordering the system. The further the system is from its equilibrium state, the less likely it would become itself again. The presence of all three types of ordering (material-energy, informational, and synergetic) is necessary as an anti-entropic activity of open stationary systems. The increasing order mechanism in open stationary systems acts at different organizational levels (microphysical, geochemical, biosphere, and social), increasing the anti-entropic potential [6]. Open stationary systems only exist and develop when they show a decrease in entropy by imports of "order" (energy, resources, information) from the external environment to the system. According to Schrödinger’s apt expression: “it [a living organism] can remain alive only by constantly extracting negative entropy from its environment ...” [32]. Consequently, the biosphere acts as a reactor that processes waste and restores the quality of the environment for socio-economic systems; biological organisms exist under the conditions of the geochemical environment.

The lower the efficiency of the systems of the upper level, the more entropy they drop for the lower level, and the more investment is needed in anti-entropy activity. The risk that this load exceeds the carrying capacity of the systems receiving it. The consequences may be: first, a decrease in the rate of anti-entropic activity, and second, the degradation and/or destruction of systems at both levels. Numerous examples illustrate the degradation of the biosphere's assimilation potential. If the adjustments of the biosphere systems lead to replacing biological species, the improvement of the public sphere is assured through socio-economic changes during social revolutions, after which a transition to a new social structure occurs. Humanity entered the era of the next transition to a new socio-economic status. This transition phase is implemented during three industrial revolutions at the same time—Industries 3.0, 4.0, and 5.0. The transition stages in combination with the change in the anti-entropic potential are the pace of the transformation processes. Disruptive technologies serve as catalysts for transformative phase transition, bringing innovative changes in production and product consumption methods, design practices, communication channels, knowledge sharing, and the skills of employees. Thus, the transition to machine production, the electrification of production systems and people's lives, the introduction of flow lines, the computerization of society, and other innovations fundamentally changed the conditions of people's lives and activities. Disruptive technologies lie at the root of all essential innovations.

The development of economic systems is linked to the emergence and spread of innovations. At the same time, revolutionary, qualitative changes are determined precisely by disruptive technologies. Thanks to them, the efficiency of the system's functioning is increased by leaps and bounds (times or even tens of times). Such is the transition of photography and filmmaking to digital technologies, which made it possible to reduce the cost of the relevant processes tenfold. In addition, new functional possibilities have opened up—for example, instant image transmission over long distances. The dynamic characteristics of the spread of innovations play a vital role. They determine the peculiarities of changes in economic systems over time and patterns of transformation of system components (algorithm, program of actions, characteristic recurring periods).

As a rule, the trend concept is primarily associated with information characteristics. Such factors are direction, orientation, and vector. However, the system's state, which is summarized by the trend of its development, inevitably affects two more components of the trialectic mechanism of system formation, namely, its material and synergetic ones. Starting first determines the energy potential of the system and its ability to perform power functions. The second defines the connections that integrate the system's individual components into a single system whole, as well as connect the system itself with the external environment.

The diagram in Figure 1 illustrates three technological factors that are essential for the development of an additive economy during the transition to a new socio-economic phase. These factors are grouped based on their roles in driving this transformation. It's important to note that these groups are interdependent, as each factor's influence arises from the interaction of multiple underlying principles. The technological factors are influenced by three natural principles: material, informational, and synergetic.

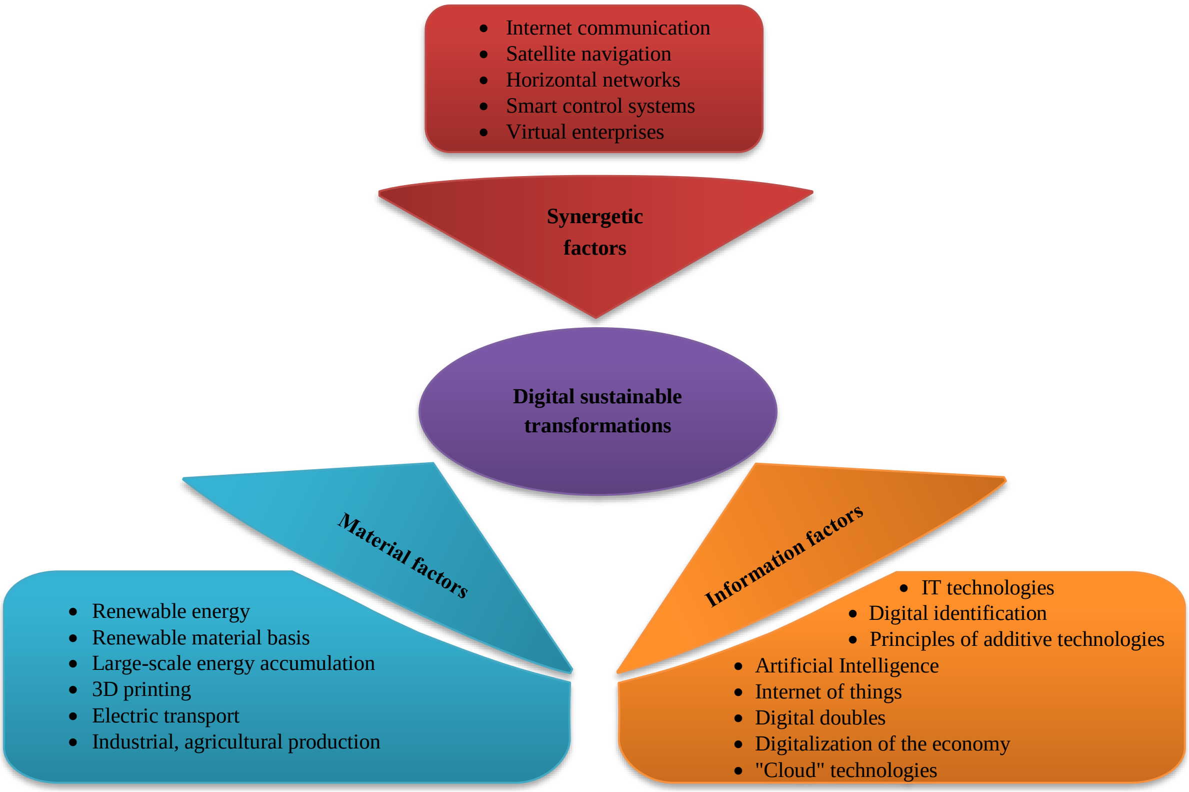


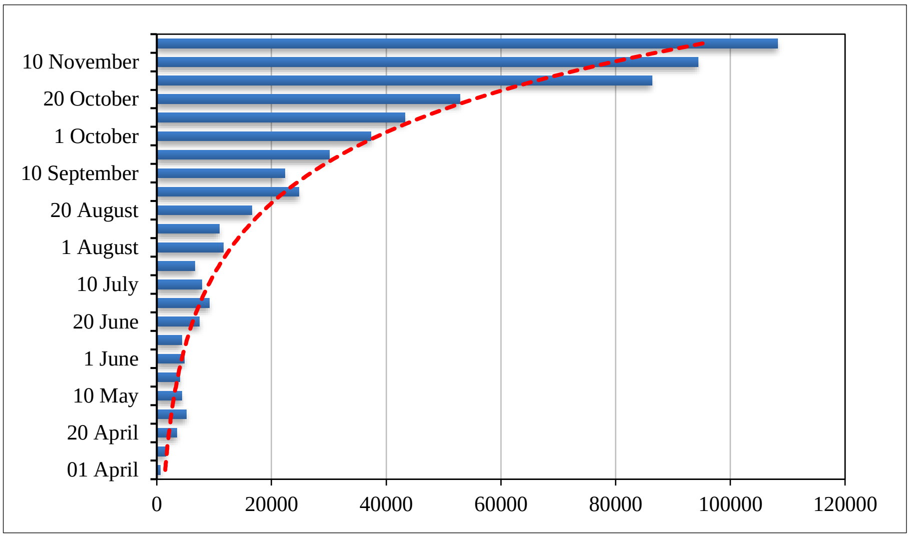
Figure 1. Basic technological factors that create prerequisites for the formation of sustainable economy

The material principle represents the physical and tangible aspects of technological advancements, such as resources and production capacities. The informational principle pertains to data, knowledge, and digitization processes that enhance technological efficiency and innovation. Finally, the synergetic principle refers to the combined effects and collaborative interactions between technologies, leading to emergent properties that drive economic growth and transformation. Although these technological factors are categorized into specific groups for analytical clarity, their full potential can only be realized through the interaction and integration of all three principles. The combined influence of material, informational, and synergetic factors forms the foundation for the emerging additive economy, enabling economies to evolve toward more sustainable, efficient, and innovation-driven structures.

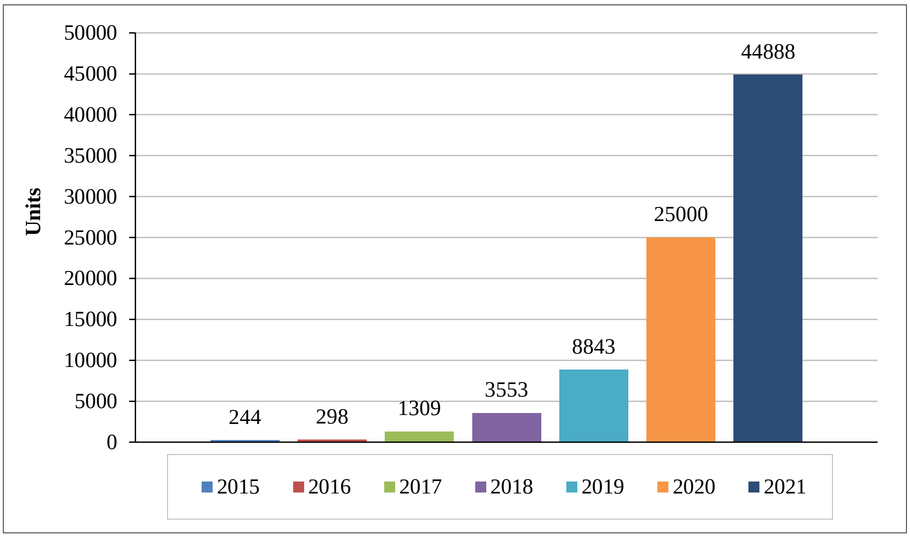
3. Results

The modern transition to a new socio-economic state is accompanied by a surge of anti-entropic activity due to a significant increase in the efficiency of production and consumption. Intensification of anti-entropic activity results in a significant reduction of the anthropogenic impact on the natural environment due to a decrease in the energy intensity and dematerialization of the production. As a consequence, socio-economic systems export less entropy to ecosystems. When the negative consequences on the environment are reduced and the efficiency of the production process increases, the total entropic activity is reduced, and this contributes to negative entropy.

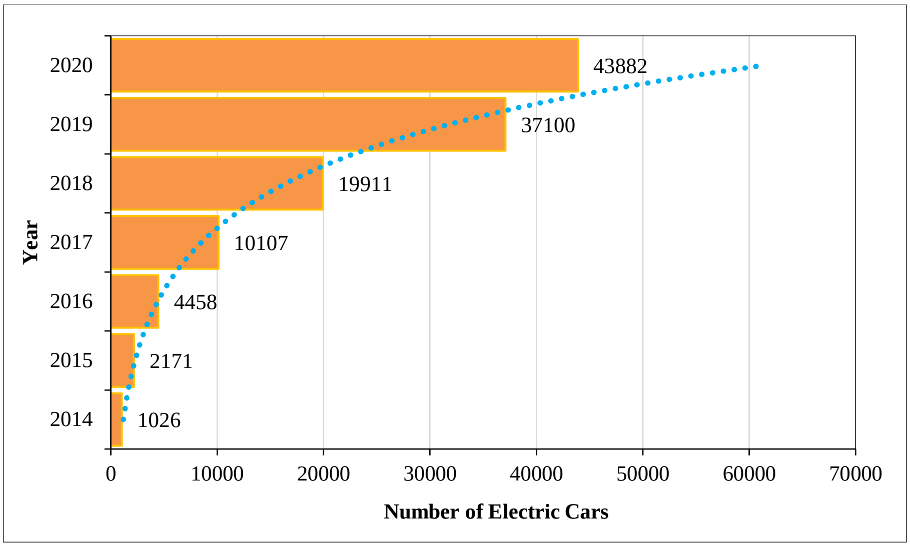
The estimation of anti-entropic activity could be performed from the two viewpoints. The first one relates to the direct impact of industrial activities on the natural environment and humans. The second one relates to the environmental consequences associated with the previous stages of production, i.e., materialized in the resources and energy used for this process. This research showed that the processes of the spread of modern disruptive technological innovations (intensification of anti-entropic activity) have specific properties that make them similar to the methods of epidemic phenomena of viral diseases spread. Therefore, the phenomenon can be called a quasi-viral spread of technological innovations. Figure 2 presents a comparative analysis of the spread of the COVID-19 disease by month in Ukraine and changes in various indicators related to the spread of modern sustainable technologies. Experiencing the COVID-19 virus in quarantine, little attention was provided to the universality of its properties. The basis of any formation relates to productive forces, of which the information core is technology. From the entropy point of view, two technological principles are important for socio-economic systems: the principle of obtaining energy and the principle of material processing. The lower the specific production of entropy (per unit of production) in each process, the lower the stress on the natural systems supporting the process, and the higher the efficiency of the functioning of an anti-entropic socio-natural potential. The transformation processes reveal signs of a quasi-viral phenomenon. The main of these features is that information determines the edges of the system and becomes the subject of influence. The critical factor in a biological organism is the cell nucleus containing the genetic code. In the economic system, this function is performed by the production, which ensures the implementation of the information code of the existing formation. For the economic system, the virus "infecting" the economic systems is innovation. Currently, the system (as in the case of a biological organism) has insufficient time to develop an "antidote" (effective mechanisms of negative feedback) to neutralize the virus. Disruptive technologies provide a basis to compare the spread of technological innovations with the processes of virus spread during pandemics.



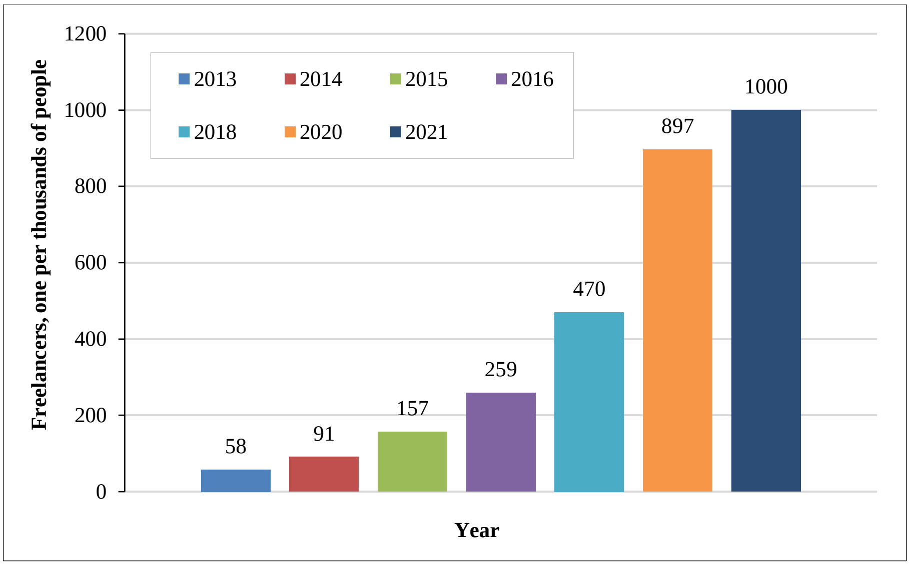
(a) The spread of COVID-19 in Ukraine in 2020



(b) Yearly data on the spread of private SPPs in Ukraine [33]



(c) Yearly data on the distribution of electric cars in Ukraine



(d) Yearly data on the number of freelancers in Ukraine

Figure 2. A comparative analysis of the COVID-19 virus spread dynamics and the adoption of sustainable technologies in Ukraine

The data in Table 1 illustrates the significant growth and adoption of various critical and innovative technologies from 2010 to 2020. These indicators provide insights into the expansion of digital connectivity, energy transition, electric mobility, and automation, reflecting transformative technological progress in multiple sectors. This data underscores the rapid diffusion of innovative technologies driven by digitalization, sustainability efforts, and advances in automation, collectively shaping modern industries and societal functions.

Table 1. Dynamics of several indicators that show the critical, innovative technologies spreading (the table is based on references [34–50]

No.	Indicator	Year / value	
		2010	2020
1	Unique mobile phone users (millions)	3250	5170
2	PC users (millions)	1300	5200
3	Internet users (millions)	2023	4930
4	Social media users (millions)	970	4000
5	Renewable energy share, (without hydro, %)	5	15
6	World energy storage capacity (GW/GWh)	2/4	12/21
7	Number of electric cars (globally, thousands)	17	10500
8	3D printers (thousands)	3	700
9	Industrial robots (thousands)	1200	3000

The conducted research allowed us to formulate the regularities of the technological innovations spread in general and the peculiarities of the quasi-viral nature of the current process. Any qualitative changes, like the functioning of the technological complex, leading to technical revolutions, begin with introducing a new technological principle from the outside into the existing production system, which changes the information algorithm of the transformation of materials, energy, and information during the production process. This bear resembles the process of infecting the body with a virus, which, penetrating the body, changes the informational algorithm of metabolism, including the exchange of substances, energy, and information within the body. When creating startups, this innovation can originate from individual inventors, the scientific realm, specialized engineering organizations, or associations comprising experts from different fields. A change in the information algorithm which serves as a guiding principle in production technology necessitates the restructuring of other components within the trialectic mechanism involved in the formation of a technological complex. These components include the material basis, synergetic factors (connections, communications), and the general reproductive phenomenon of the technological complex, as shown in Figure 3.

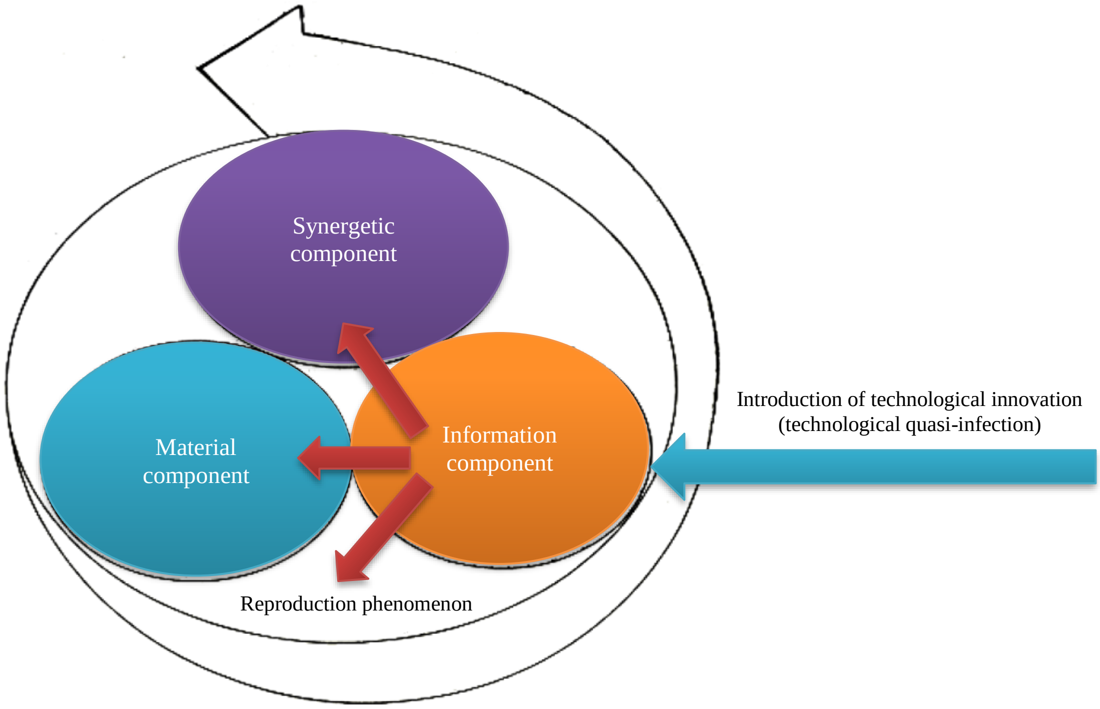


Figure 3. Scheme of technological innovation impact on the trialectic mechanism of forming a technological complex

The application and adoption of modern sustainable innovations have reached unprecedented levels, exhibiting similarities to the rapid spread of viral diseases. The comparative analysis of these phenomena made it possible to formulate a definition of the quasi-viral nature of the reach of technological innovations and systematize the critical features of this process.

The quasi-viral nature of the technological innovations spread should be recognized as the development of transformational processes due to the anticipatory change of the informational component of the technological complex (the fundamental principle of its functioning) using methods that simulate the course of viral infection.

The key features or signs of the quasi-viral spread of innovative technologies as formulated by the authors are depicted in Figure 4.

The main features of the quasi-viral spread of technological innovations are:

(i) The leading component of technology change is the informational factor, not the material one. New technology wins not because it is more powerful or productive but because it is much more efficient (sometimes many times) than the existing one.

This happened with the implementation of technologies for the performance of solar power plants (particularly those built on PV effects). After the introduction of information about new technological principles into the system of electricity production, designs for their material embodiment began to be developed, based on which capacities for mass production of fundamentally new types of equipment for electricity generation were created. New technologies have brought about a significant transformation in the foundational elements of synergy, encompassing organizational ties, communications, and industrial relations.

One notable shift is the transition from traditionally centralized large-scale electricity production enterprises to a more decentralized model comprising small-scale production units, such as solar panels, which are seamlessly integrated into unified information and energy networks. This ongoing process means a shift from spatial concentration, enabling a distributed and interconnected energy system.

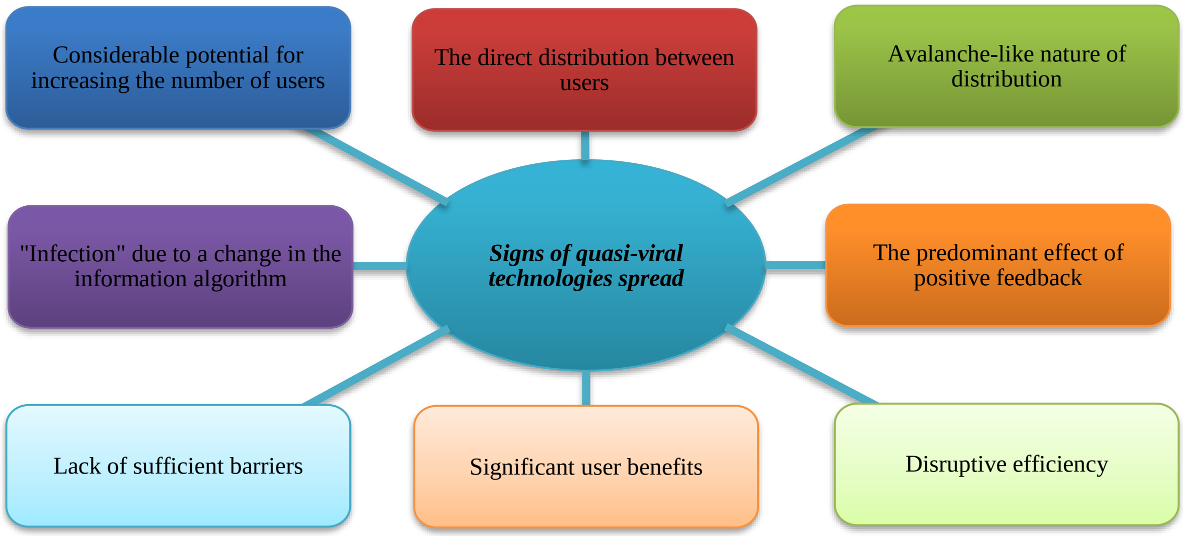


Figure 4. Key features of the quasi-viral spread of disruptive sustainable innovations

(ii) Quasiviral sustainable technology demonstrates its economic, social, and environmental advantages, making it extremely attractive to a wide range of potential users.

(iii) Traditional technology that is currently widely used is not able to compete with the new one due to the mentioned advantages of the latter. Similarly, the body usually cannot initially defend itself against the virus.

In a series of examples that illustrate the specified feature, one of the first places belongs to digital photography, which became the result of two technologies: chemical analog photography and the instant Polaroid photo.

At Kodak, a well-known company in the field of photo production, the sales of the film reached a peak in 2001, after which it began to decline. From 2000 to 2010, the need for cinema decreased ten times. In the early 2010s, the reduction became an avalanche. In 2012, the company filed for bankruptcy.

Another well-known company, Polaroid, shared the fate of Kodak. The company specialized in fast photography. In 1970–1980, it gained tremendous popularity. Thanks to patent protection, the company felt almost no pressure from competitors for practically three decades. In the early 2000s, the Polaroid company also went bankrupt, unable to withstand competition from digital photography, the spread of which was quasi-viral. The decisive role was played by the colossal advantages of digital technologies, which did not require either film or reagents at all whiles having several fundamentally new functional capabilities compared to traditional competitors (instant image acquisition, dematerialization of the processes of transfer and storage of prints, preservation of high image quality, minimization expenses).

(iv) Viral sustainable technology is able to spread among a much more comprehensive range of users than its alternative counterparts (traditional technologies).

In particular, solar and wind power plants, as well as 3D printers, can be used by ordinary private users. While traditional energy and traditional machine-building technologies are suitable only for use in large-scale industrial production.

(v) Quasiviral sustainable technology has significant economic advantages: relatively cheap implementation, affordable implementation costs to many users, and quick payback of invested costs.

(vi) Informational signals regarding the profitability of the implementation and use of quasi-viral sustainable technologies can be transmitted directly from the user to the user.

(vii) The progressive (avalanche-like) nature of the processes of the spread of quasi-viral technologies is observed when in short periods, there is a significant increase in the intensity of the use of quasi-viral technologies (in particular, the number of users increases significantly).

(viii) With the quasi-viral sustainable spread of technologies, positive feedback mechanisms regarding changes in the state of the economic system prevail. The system does not have time to react to the changes taking place and balance its shape due to the use of harmful feedback mechanisms. We can name several modern productions that have signs of viral technologies:

- Renewable energy (solar, wind, bio);
- 3D printing;
- Electric transport;
- Accumulation of energy;
- IT technologies;
- Digital technologies in photo and film production;
- Internet of things;
- Smart management system;
- Artificial Intelligence;
- Virtual and augmented reality;
- Cloud technologies.

Here are the Top 5 Emerging technologies that showed themselves to the maximum in 2023, and which, thanks to their functional properties, promise to turn into viral breakthrough technologies (see Table 2).

Table 2. Top 5 Sustainable technologies of 2023, which, thanks to their functional properties, promise to turn into viral breakthrough technologies (based on [51–53])

The name of the technology	Characteristics
Flexible batteries	• Key advantages: flexibility, can be easily twisted, bent, stretched, ability to recharge. • Fields of application: health monitoring (in wearable medical devices and biometric sensors), flexible displays, "smart" clothing, flexible watches, environmental monitoring. • Beneficiary sectors (potential beneficiaries): people, industry, economy, social sphere (social sphere), ecosystems (ecosystems). • Market Outlook: The global flexible battery market is projected to grow by 23% annually through 2027, at approximately $50 million per year. The main drivers of growth are the proliferation of wearable devices and trends in the miniaturization and flexibility of electronics.
Generative AI	• Fields of application: scientific activity, the space industry (in particular, the time of creating flight instruments can be reduced by 10 times with the improvement of product quality), architecture, design of premises and household appliances, engineering, food industry, journalism, health care, ecology. • Market prospects: the development of AI has enormous market prospects; if in 2023 the global AI market was estimated at $57 billion, then by 2025 it is forecast at the level of $190 billion.
Wearable plant sensors	• Key advantages: allow continuous individual monitoring of plant parameters (temperature, humidity, content of substances); in combination with AI, opportunities are created for optimizing irrigation, fertilizers, herbicides and pesticides, as well as detecting early signs of diseases; significant minimization of dimensions and low energy consumption; allow to reduce costs in agricultural production while increasing productivity and improving product quality. • Fields of application: agricultural production, forestry, control of ecosystems. • Projected result of implementation: 70% increase in global food production.
Space omics	• Key advantages: makes it possible to detect deviations in the work of organs at the molecular level; advanced visualization methods are combined with high-resolution DNA sequencing; extracting from a certain organ its particles the size of only one cell (cell) makes it possible to observe cell architecture and biological processes in unprecedented detail. • Fields of application: health care, scientific activity, veterinary medicine, agricultural production, ecosystem control. • Market prospects: the possibility of receiving revenues from the implementation of the technology in 2030 is predicted to be $587 million.
Designer phages	• Key advantages : allow you to fight against harmful viruses and bacteria with the help of useful programmed viruses - phages ; when an organism is infected with bacteria or viruses, a bioengineered virus - a phage , which is able to carry out a bioengineered set of genetic instructions and change the functions of harmful bacteria and viruses, is found in them; as a result, a therapeutic molecule is created or harmful bacteria or viruses become sensitive to the drug. • Fields of application: scientific activity, health care, agricultural production, plant breeding, veterinary medicine, ecosystem control. • Market Outlook: Phage therapy is attracting significant venture capital as it has the potential to revolutionize human, animal and plant health monitoring.

The spread of these technologies demonstrates synergetic effects. When these technologies are implemented in the same temporal field, they exhibit the properties of mutual reinforcement of actions. As a result, their distribution processes are accelerated compared to their autonomous distribution. Together, the indicated cluster of innovations is a decisive driving force for implementing a phase transition through the processes of modern industrial revolutions: Industries 3.0, 4.0, and 5.0 towards ensuring sustainable development.

4. Discussion

The conducted studies need to provide an opportunity to give an unequivocal answer to several questions. One of them is “To what extent phenomena with signs of quasi-viral spread, which have a different nature of their formation, but occur next to each other in space and time, are related to each other”? Three different types of phenomena can be named: first, the epidemic of COVID-19; second, the processes of diffusion of technological innovations are interconnected; third, various social phenomena. The latter include, for example, the mass spread of freelancing with the activation of intellectual and creative components of human capital.

The COVID-19 pandemic also led to the transformation of economic relations in the direction of digitalization, automation, real-time tracking of technological and economic processes, reduction of specific costs, and improvement of system functioning efficiency.

On the other hand, the specified technological innovations contribute to solving complex economic, social, and environmental problems. They also bring the achievement of the Sustainable Development Goals closer.

The study of mutual relations between the results of the digitalization of production systems and the transformation of the social status of human capital deserves special attention. First, we are talking about a significant increase in intellectualization, creativity, and personalization.

A separate manifestation of this is the extremely rapid rate of spread and development of freelancing. In this, it is possible to trace, on the one hand, the influence of quasi-viral processes of the reach of modern technological innovations on the conditions of human activity. Thanks to this, highly favorable opportunities for human self-organization in the global space of economic activity are created. On the other hand, the change in the social status of human capital and a person's working conditions are beginning to play the role of catalyzing and accelerating the processes of creating and spreading technological innovations. A new intellectualized person begins to request a higher information level of production systems.

Another subject of research should be the cause-and-effect relationships of these issues with sustainable development goals. Prerequisites are created for achieving the key objective of sustainable development, namely the priority social development of a person. This is also a direct goal of the implementation of Industry 5.0.

Determining the degree of mutual connection between individual components of various cluster processes of the spread of technological innovations is also debatable. The analysis showed an abnormally close timing of the start of the reach of technological innovations, primarily for the creation of the Internet of Things (Table 3). Its formation is the core of Industry 4.0.

The decisive events that marked the beginning of the spread of twelve critical technologies necessary for the formation of the Internet of Things (for example, the appearance on sale of the prototype of a vital device for this technology) took place almost simultaneously with a difference of 1-3 years. Seven of these 12 events happened in 1973.

Such close timing of the start of the spreading processes of these technological innovations necessitates the need to conduct more in-depth research into the cause-and-effect relationships of the occurrence of such a weird phenomenon, given that the cycles of their creation took place at different times, in other countries, by various authors. In particular, the first computer was created in Great Britain, the Internet and GPS in the USA, Wi-Fi in New Zealand, and the 3D printer in Japan. These mentioned cycles represent highly complex and long-lasting phenomena, which include the invention of the basic principle, bringing it to materialization in a concrete product, the development of industrial design, adaptation to the conditions of mass consumption and sale, etc.

Attention should be paid to the complex nature of the dynamics of the processes of spreading technological innovations and developing relevant trends. At the same time, once a trend is established, its flow begins to influence the configuration of other interrelated trends, which are necessary for the dissemination of technological inno vations. The reason is that the primary trend begins to impose its demands on its underlying subtends, which ensure its formation.

Table 3. Dates and events related to technological innovations for the IoT creation

No.	Technology	Year / event	
		Critical start of technology	**The build starts for the IoT**
1	Personal computer [54]	1973 release of the prototype	2010 1,5 billion users
2	Internet [54–56]	1973 international status	2010 2 billion users
3	Mobile phone [54, 57]	1973 release of the prototype	2010 about 3 billion subscribers
4	Wi-Fi [58, 59]	1971 The first realization of the idea	2009 adopting of official standards
5	Renewable energy [60, 61]	1971 The first cases of renewable energy use	2010 world SES capacity is 1 GW
6	3D printer [62, 63]	1981 release of the prototype	2010 a kidney is printed
7	Digital technology [64, 65]	1973 industrial digital recording of information	2010 98% of digital information
8	Artificial intelligence [66, 67]	1972 Prolog is created	2010 artificial brains, antibodies, neurons
9	RFID tags [68, 69]	1973 the first demonstration	2010 wide distribution (libraries, shops, passports)
10	GPS [70, 71]	1973 initiating the program	2010 civil status
11	Robot [72]	1968 production of industrial design	2010 wide distribution
12	Drone [73]	1969 production of industrial prototypes	2010 widely used in many sectors
13	“Cloud” [74, 75]	1972 the virtual	2011 standards adopted
	Internet of things	2012 Start of the cycle	

The results of the spread of specified clusters of technological innovations in the processes of the current phase transition cause qualitative changes in economic systems, the most significant manifestations of which are:

- Transition to renewable material and energy resources.
- Formation of a circular economy.
- Dematerialization of industrial metabolism (production processes and communication links);
- Mass use of efficient energy storage technologies.
- Formation of functions of self-optimization and self-improvement of technical systems based on artificial intelligence.
- Achieving the goals of biodiversity conservation and ecosystem preservation.
- Control over processes in society and nature through the “Cloud”.
- Transition to the goals of priority social development on a person's basis.

As we can see, various indicators, which can be called entropy prices, create a criterion basis for a generalized assessment of the results of the spread of technological innovations and approaching the achievement of sustainable development goals.

The similar quasi-viral character of development could be seen for other recent technologies (including, PC users, Internet users, social media users, global storage capacity, etc.) (see Figure 5).

The assumption of such a general goal of realizing a significant number of divers in terms of content and form of manifestation of technological innovations determines the existence of a universal concrete criterion for achieving such a goal. One of the most appropriate categories for this is the entropy index

The specified changes will contribute to the activation of human anti-entropy activity, which, in particular, will be accompanied by a sharp increase in human information production and a reduction in the impact on the material components of the planet's biosphere. The latter will bring the formation of prerequisites for sustainable development closer. We will give only a few examples. Since 2010, the amount of global data produced by humans has increased 60 times, from 2 zettabytes to 120 zettabytes in 2023 [76] (a similar increase can be considered as another quasi-viral process). According to our consolidated estimates, the specific economic losses from violating biosphere components over the entire cycle of production and consumption of 1 kWh of electricity in fuel energy are 13-22 times higher than in renewable energy. This indicator is a first approximation as the entropy price of production and consumption of a unit of such a product as electricity. With a more detailed consideration of all the components of the formation of the specified indicator, this difference can increase to dozens of times.

The total estimate of specific environmental and economic losses per unit of material products manufactured by the 3D printing method is 5-7 times lower than in traditional production processes.

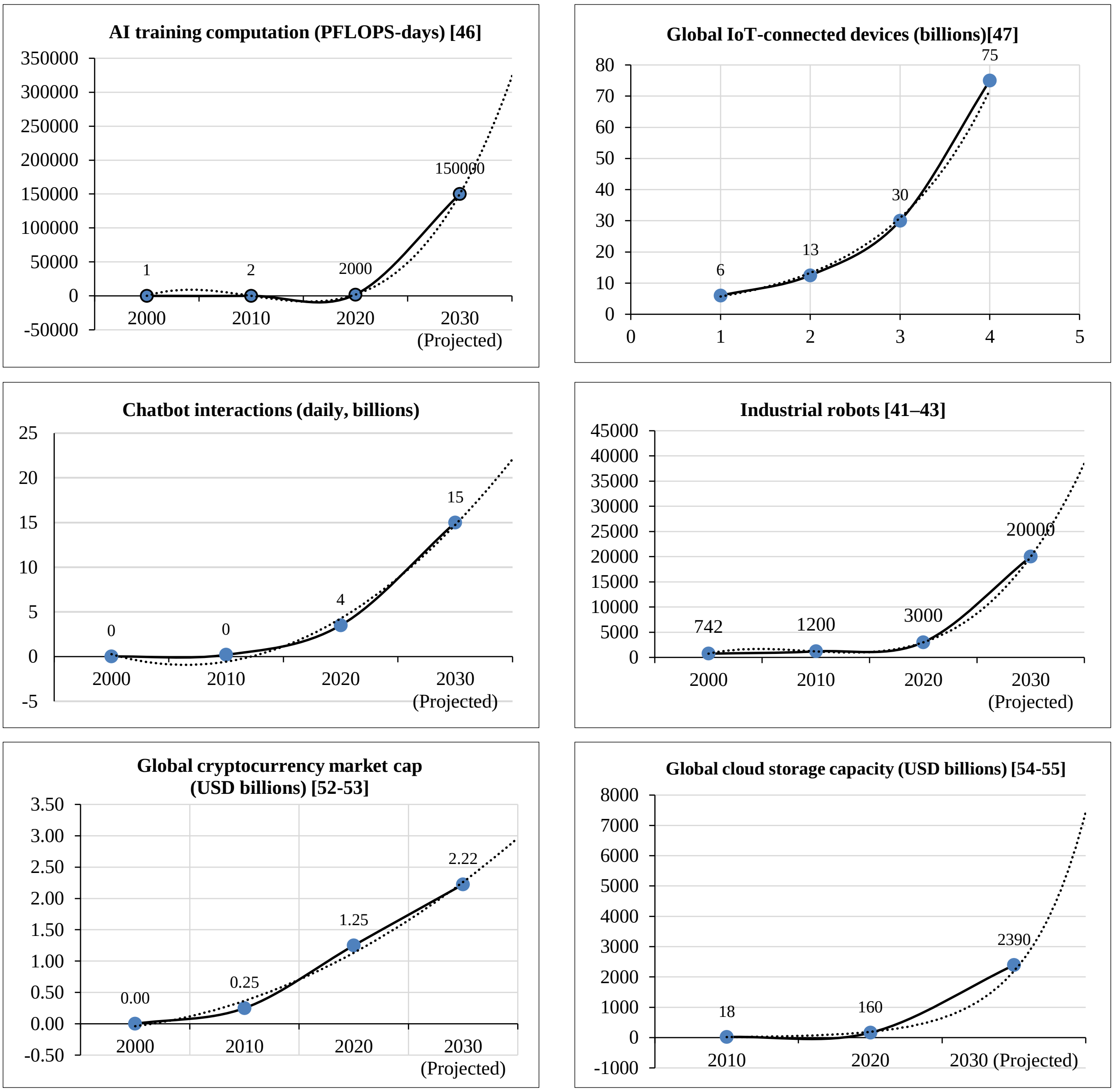


Figure 5. Quasi-viral character of recent technological development

5. Future Research

Two key directions for further research are:

The first direction is related to answering an important question: is there a common goal (a kind of attractor) towards which civilization is heading in implementing the specified cluster of technological innovations? The second direction depends on the answer to the first. If the set goal exists, what is the general nature of measuring its achievement?

As a working hypothesis, the authors express the opinion that such a goal (conditionally – a common attractor) to which the implementation of the specified phase transition to a new socio-economic formation approach exists. At the abstract level, it can be formulated as achieving sustainable development.

The desire to reduce reliance on fossil fuels and combat climate change has made the shift to renewable energy a central focus of global energy strategies during the past few decades. This study highlights important shifts and patterns in the consumption of renewable energy from 1965 to 2023 in several different nations and areas.

Globally, the proportion of primary energy consumption derived from renewable sources has increased to 14.56% in 2023 from 6.45% in 1965, a shift of 126%. Significant gains have been seen in some regions, such as South America and Central America. South America's share increased by 250% to 38.35%, while the combined share of Central and South America increased by 268% to 35.39%. This suggests that these areas have a strong dedication to renewable energy, which is probably encouraged by the abundance of natural resources like hydroelectric power. A comparative analysis of renewable and non-renewable sources across regions is depicted in Figure 6. The figure offers a comprehensive overview of the global energy landscape, illustrating the consumption and production patterns of both renewable and non-renewable energy sources across different regions in 2024.

- ***Notable National Performances***: The country with the largest relative rise in the share of renewable energy was Belgium, where it went from almost zero (0.19%) to 12.53%, an astounding 6331% increase. Hungary too experienced an incredible rise, going from 0.12% to 10.98%—a 9057% relative growth that is among the biggest ever observed. The share of renewable energy in the UK went from 0.59% to 20.52%, a 3385% relative rise that indicates a huge shift in policy in favor of renewables.
- ***Major Changes***: Both Canada and Brazil, who are resource-rich nations, have raised their investments in renewable energy dramatically; Brazil's has gone from 25.14% to 29.26%, while Canada's has increased from 27.55% to 50.33%. Due to its ambitious energy transition policy, Germany saw one of the largest absolute gains in the use of renewable energy, going from 1.61% to 24.39%, a change of 22.78 percentage points.
- ***Reductions and Fears***: There have been drops in the use of renewable energy in a few nations. Iran saw a decline from 5.23% to 1.82%, mostly because of its excessive reliance on fossil fuels. Taiwan had a decline from 10.87% to 5.26%, suggesting possible difficulties in increasing investments in renewable energy.
- ***Geographical Evaluation***: The European Union has increased its share of renewable energy from 6.71% to 21.98%, demonstrating its leadership in this area. This emphasizes the EU's strong ambitions for renewable energy and its dedication to environmental sustainability. Africa saw a slight increase, rising from 5.74% to 9.83%, however there were significant regional differences. For example, a minor decline was observed in Middle Africa, suggesting regional differences in energy investment and access.

The world is clearly moving toward renewable energy; however, some nations and regions have made more progress than others. The information emphasizes how important natural resources, economic conditions, and political will are in influencing the use of renewable energy. To meet the goals of global sustainability, the adoption of renewable energy must be accelerated globally, and this will require sustained investment and supportive legislation.

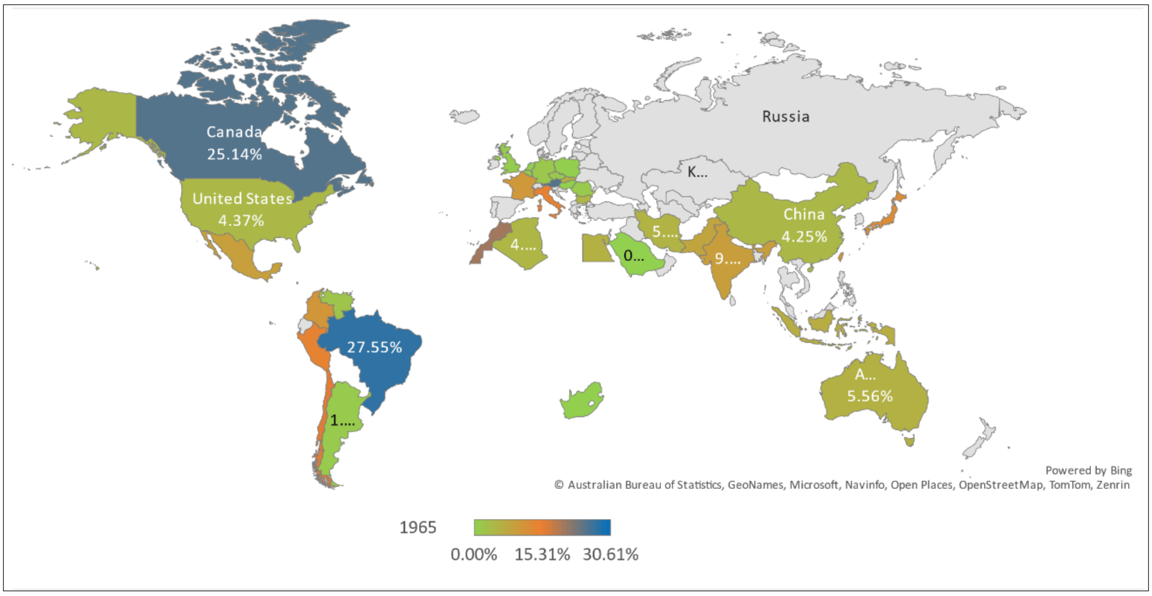


Figure 6. Global Energy Consumption and Production Trends (2024): A Comparative Analysis of Renewable and Non-renewable Sources Across Regions

By significantly increasing the efficiency of the functioning of economic systems and, at the same time, considerably reducing the impact on the planet's ecosystems, modern technological innovations, in one way or another, bring humanity closer to achieving all 17 strategic goals of sustainable development (Sustainable Development Goals), also known as “Global Goals”. In abbreviated form, they sound like this: 1) overcoming poverty; 2) elimination of hunger; 3) provision of health and well-being; 4) provision of quality education; 5) gender equality; 6) clean water and sanitation;

7) inexpensive and clean energy; 8) ensuring sustainable economic growth and decent work; 9) creation of the necessary infrastructure; 10) reduction of inequality in countries; 11) creation of sustainable settlements; 12) provision of sustainable consumption and production models; 13) prevention of climate change; 14) preservation of marine ecosystems; 15) ensuring the integrity of terrestrial ecosystems; 16) ensuring peace, justice, and effective public institutions; 17) strengthening partnership in the interests of sustainable development (World, 2015).

The advancement of scientific research in specific areas will contribute to establishing an objective assessment system for justifying strategic planning decisions and implementing a purposeful policy to manage society's resource potential.

6. Conclusions

The current stage of social development is marked by a phase transition to a new socio-economic formation, which takes place during three industrial revolutions: Industries 3.0, 4.0, and 5.0. Technological innovations are the driving force of transformational processes. Their essential feature is the quasi-viral nature of introduction and distribution.

The quasi-viral nature of the spread refers to the development of transformational processes through the anticipatory change of the informational component of the technological complex (the fundamental principle of its functioning) using methods that simulate the course of viral infection.

The study of the nature of quasi-viral processes allowed formulation the critical features of quasi-viral technological innovations, which can be briefly defined as follows: 1) "infection" due to a change in the information algorithm; 2) essential advantages of users; 3) lack of sufficient barriers; 4) significant potential for increasing the number of users; 5) direct distribution between users; 6) disruptive efficiency; 7) avalanche-like nature of distribution; 8) the predominant effect of positive feedback.

The results obtained leave several debatable issues. One of them is: to what extent the emergence and spread of the mentioned technological innovations are related to the development of other socio-economic phenomena, in particular, the epidemic of COVID-19 and the processes of intellectualization and creativity of human capital, manifested through the activation of freelance forms of work.

A debatable issue is determining the degree of mutual connection between individual processes within clusters of the spread of unique technological innovations. An important issue is a deeper study of the connections between the processes of quasi-viral diffusion of technological innovations and the achievement of sustainable development goals.

The article hypothesizes that implementing various clusters of quasi-viral technological innovations has a common goal (conditionally common attractor), which can be formulated as the formation of sustainable development by gradually achieving its key objectives. At the theoretical level, the amount of entropy reduction in the functioning of the planet's social and natural anti-entropy potential can be a general measure of achieving the specified goal.

The result of the spread of these quasi-viral innovations should be a significant dematerialization of industrial metabolism, provision of functions of self-organization and self-improvement of social systems, preservation of biodiversity and ecosystems of the planet, and transition to priority social development of man. All together brings civilization closer to the formation of the foundations of sustainability.

7. Declarations

7.1. Author Contributions

Conceptualization, L.M., L.V., O.K., and K.L.; methodology, L.M., L.V., S.S., O.K., and K.L.; validation, L.M., L.V., and S.S.; formal analysis, L.M. and S.S.; resources, L.M., L.V., O.K., and K.L.; data curation, L.M. and S.S.; writing—original draft preparation, L.M., L.V., O.K., and K.L.; writing—review and editing, L.M. and S.S.; visualization, L.M., L.V., and S.S.; supervision, L.M., O.K., and K.L.; project administration, L.M., O.K., and K.L.; funding acquisition, L.M., O.K., and K.L. All authors have read and agreed to the published version of the manuscript.

7.2. Data Availability Statement

The data presented in this study are available in the article.

7.3. Funding

This research was conducted as part of Jean Monnet Module «Disruptive technologies for sustainable development in conditions of Industries 4.0 and 5.0: the EU Experience», (101083435-DTSDI-ERASMUS-JMO-2022-HEI-TCH-RSCH), focuses on creating a theoretical and practical foundation for the integration of advanced technologies such as automation, artificial intelligence, and smart manufacturing in EU and Ukraine.

7.4. Acknowledgments

The authors would like to express their sincere gratitude to the funders of the scientific projects that supported this research. This work was prepared as part of the project «Disruptive technologies for sustainable development in conditions of Industries 4.0 and 5.0: the EU Experience», (101083435-DTSDI-ERASMUS-JMO-2022-HEI-TCH-RSCH), which provided the foundation for exploring the integration of advanced digital technologies.

7.5. Institutional Review Board Statement

Not applicable.

7.6. Informed Consent Statement

Not applicable.

7.7. Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

8. References

[1] Alam, S., Zhang, J., Shehzad, M. U., Boamah, F. A., & Wang, B. (2024). The inclusive analysis of green technology implementation impacts on employees age, job experience, and size in manufacturing firms: empirical assessment. Environment, Development and Sustainability, 26(2), 4467–4486. doi:10.1007/s10668-022-02891-6.

[2] Razzaq, A., Wang, Y., Chupradit, S., Suksatan, W., & Shahzad, F. (2021). Asymmetric inter-linkages between green technology innovation and consumption-based carbon emissions in BRICS countries using quantile-on-quantile framework. Technology in Society, 66, 101656. doi:10.1016/j.techsoc.2021.101656.

[3] Elmawazini, K., Chkir, I., Mrad, F., & Rjiba, H. (2022). Does green technology innovation matter to the cost of equity capital? Research in International Business and Finance, 62, 101735. doi:10.1016/j.ribaf.2022.101735.

[4] Haldar, A., & Sethi, N. (2022). Environmental effects of Information and Communication Technology - Exploring the roles of renewable energy, innovation, trade and financial development. Renewable and Sustainable Energy Reviews, 153, 111754. doi:10.1016/j.rser.2021.111754.

[5] Chen, C., Pinar, M., & Stengos, T. (2021). Determinants of renewable energy consumption: Importance of democratic institutions. Renewable Energy, 179, 75–83. doi:10.1016/j.renene.2021.07.030.

[6] Melnyk, L. (2021). Socio-natural antientropic potential: the role of economy and innovations. Environment, Development and Sustainability, 23(3), 3520–3542. doi:10.1007/s10668-020-00730-0.

[7] Bollaert, H., Lopez-de-Silanes, F., & Schwienbacher, A. (2021). Fintech and access to finance. Journal of Corporate Finance, 68, 101941. doi:10.1016/j.jcorpfin.2021.101941.

[8] Bahoo, S., Cucculelli, M., & Qamar, D. (2023). Artificial intelligence and corporate innovation: A review and research agenda. Technological Forecasting and Social Change, 188, 122264. doi:10.1016/j.techfore.2022.122264.

[9] Braun, E., & Wield, D. (1994). Regulation as a Means for the Social Control of Technology. Technology Analysis & Strategic Management, 6(3), 259–272. doi:10.1080/09537329408524171.

[10] Asiaei, K., O'Connor, N. G., Barani, O., & Joshi, M. (2023). Green intellectual capital and ambidextrous green innovation: The impact on environmental performance. Business Strategy and the Environment, 32(1), 369–386. doi:10.1002/bse.3136.

[11] Mohd Suki, N., Mohd Suki, N., Afshan, S., Sharif, A., Ariff Kasim, M., & Rosmaini Mohd Hanafi, S. (2022). How does green technology innovation affect green growth in ASEAN-6 countries? Evidence from advance panel estimations. Gondwana Research, 111, 165–173. doi:10.1016/j.gr.2022.06.019.

[12] Zhu, C., Yue, J., & Chen, J. (2022). Green Product Development and Order Strategies for Retailers. Sustainability (Switzerland), 14(15), 9556. doi:10.3390/su14159556.

[13] Behera, P., & Sethi, N. (2022). Nexus between environment regulation, FDI, and green technology innovation in OECD countries. Environmental Science and Pollution Research, 29(35), 52940–52953. doi:10.1007/s11356-022-19458-7.

[14] Cai, X., Zhu, B., Zhang, H., Li, L., & Xie, M. (2020). Can direct environmental regulation promote green technology innovation in heavily polluting industries? Evidence from Chinese listed companies. Science of the Total Environment, 746, 140810. doi:10.1016/j.scitotenv.2020.140810.

[15] Zhang, Y., Hu, H., Zhu, G., & You, D. (2023). The impact of environmental regulation on enterprises' green innovation under the constraint of external financing: evidence from China's industrial firms. Environmental Science and Pollution Research, 30(15), 42943–42964. doi:10.1007/s11356-022-18712-2.

[16] Du, K., Cheng, Y., & Yao, X. (2021). Environmental regulation, green technology innovation, and industrial structure upgrading: The road to the green transformation of Chinese cities. Energy Economics, 98, 105247. doi:10.1016/j.eneco.2021.105247.

[17] Lin, Z., Liang, D., & Li, S. (2022). Environmental Regulation and Green Technology Innovation: Evidence from China's Heavily Polluting Companies. Sustainability (Switzerland), 14(19), 12180. doi:10.3390/su141912180.

[18] Lu, N., Wu, J., & Liu, Z. (2022). How Does Green Finance Reform Affect Enterprise Green Technology Innovation? Evidence from China. Sustainability (Switzerland), 14(16), 9865. doi:10.3390/su14169865.

[19] Sharif, A., Kocak, S., Khan, H. H. A., Uzuner, G., & Tiwari, S. (2023). Demystifying the links between green technology innovation, economic growth, and environmental tax in ASEAN-6 countries: The dynamic role of green energy and green investment. Gondwana Research, 115, 98–106. doi:10.1016/j.gr.2022.11.010.

[20] Sun, X., Tang, J., & Li, S. (2022). Promote Green Innovation in Manufacturing Enterprises in the Aspect of Government Subsidies in China. International Journal of Environmental Research and Public Health, 19(13), 7864. doi:10.3390/ijerph19137864.

[21] Sánchez-Sellero, P., & Bataineh, M. J. (2022). How R&D cooperation, R&D expenditures, public funds and R&D intensity affect green innovation? Technology Analysis and Strategic Management, 34(9), 1095–1108. doi:10.1080/09537325.2021.1947490.

[22] Zhao, J., Pongtornkulpanich, A., & Cheng, W. (2022). The Impact of Board Size on Green Innovation in China's Heavily Polluting Enterprises: The Mediating Role of Innovation Openness. Sustainability (Switzerland), 14(14), 8632. doi:10.3390/su14148632.

[23] Zhao, Y., Peng, B., Elahi, E., & Wan, A. (2021). Does the extended producer responsibility system promote the green technological innovation of enterprises? An empirical study based on the difference-in-differences model. Journal of Cleaner Production, 319, 128631. doi:10.1016/j.jclepro.2021.128631.

[24] Sharif, A., Saqib, N., Dong, K., & Khan, S. A. R. (2022). Nexus between green technology innovation, green financing, and CO2 emissions in the G7 countries: The moderating role of social globalization. Sustainable Development, 30(6), 1934–1946. doi:10.1002/sd.2360.

[25] Obobisa, E. S., Chen, H., & Mensah, I. A. (2022). The impact of green technological innovation and institutional quality on CO2 emissions in African countries. Technological Forecasting and Social Change, 180, 121670. doi:10.1016/j.techfore.2022.121670.

[26] Habiba, U., Xinbang, C., & Anwar, A. (2022). Do green technology innovations, financial development, and renewable energy use help to curb carbon emissions? Renewable Energy, 193, 1082–1093. doi:10.1016/j.renene.2022.05.084.

[27] Drake, G. W. F. (2025). Entropy. Definition & Equation. Encyclopædia Britannica, Inc. Edinburgh, United Kingdom. Available online: https://www.britannica.com/science/entropy-physics (accessed on January 2025).

[28] Johnson, G.J. (2018). A Dictionary of Science (7th Edition). Reference Reviews, 32(2), 19-19. doi:10.1108/rr-08-2017-0181.

[29] Clark, D. K. (1860). The mechanical theory of heat. Journal of the Franklin Institute, 70(3), 163–169. doi:10.1016/0016-0032(60)90150-2.

[30] Boltzmann, L. (1974). The Second Law of Thermodynamics. Theoretical Physics and Philosophical Problems. Springer Netherlands. doi:10.1007/978-94-010-2091-6_2.

[31] Thomson, W. (1852). XLVII. On a universal tendency in nature to the dissipation of mechanical energy. The London, Edinburgh, and Dublin Philosophical Magazine and Journal of Science, 4(25), 304–306. doi:10.1080/14786445208647126.

[32] da Silva, S. L. L., & da Mata, A. S. (2021). What is life? The Physical Aspect of the Living Cell by Erwin Schrödinger. Cambridge University Press, Cambridge, United States. doi:10.1590/1806-9126-RBEF-2020-0527.

[33] Ecotechnica (2024). Home solar stations in Ukraine: New statistics for the beginning of 2020. Available online: https://ecotechnica.com.ua/uk/energy/solntse/domashnie-solnechnye-stantsii-v-ukraine-novaya-statistika-na-nachalo-2020-goda (accessed on January 2025).

[34] Statistica. (2022). Unique mobile subscribers worldwide by region 2010-2025. Statista. Available online: https://www.statista.com/statistics/740154/worldwide-unique-mobile-subscribers-by-region/ (accessed on January 2025).

[35] PR Newswire (2024). Worldwide Personal Computers Industry to 2030—Major Players Include Dell, Lenovo Group and Acer Among Others. Available online: https://www.prnewswire.com/news-releases/worldwide-personal-computers-industry-to-2030---major-players-include-dell-lenovo-group-and-acer-among-others-301318261.html (accessed on January 2025).

[36] Petrosyan, A. (2024). Internet and social media users in the world 2024. Statista. Available online: https://www.statista.com/statistics/617136/digital-population-worldwide/ (accessed on January 2025).

[37] Singleton, M. (2024). Mark Zuckerberg wants Facebook to have 5 billion users by 2030. The Verge. Available online: https://www.theverge.com/2016/2/4/10918680/5-billion-facebook-users-by-2030-mark-zuckerberg (accessed on January 2025).

[38] Hill, J. S. (2016). Renewable Energy Now Accounts For 30% Of Global Power Generation Capacity. CleanTechnica. Available online: https://cleantechnica.com/2016/09/20/renewable-energy-now-accounts-30-global-power-generation-capacity/ (accessed on January 2025).

[39] IEA. (2019). Modern renewables in SDG7: Data and Projections. International Energy Agency, Paris, France. Available online: https://www.iea.org/reports/sdg7-data-and-projections/modern-renewables#abstract (accessed on January 2025).

[40] Tu, Y. X., Kubatko, O., Piven, V., Sotnyk, I., & Kurbatova, T. (2022). Determinants of Renewable Energy Development: Evidence from the EU Countries. Energies, 15(19), 7093. doi:10.3390/en15197093.

[41] IRENA. (2019). Renewable Power Generation Costs in 2018. International Renewable Energy Agency, Masdar City, United Arab Emirates. Available online: https://www.irena.org/publications/2019/May/Renewable-power-generation-costs-in-2018 (accessed on January 2025).

[42] McCartny, R., & Xu, L. (2020). WoodMac: Global Energy Storage Capacity to Hit 741GWh by 2023. A Wood Mackenzie Business. Available online: https://www.greentechmedia.com/articles/read/woodmac-global-storage-to-reach-741-gigawatt-hours-by-2030 (accessed on January 2025).

[43] Proctor, D. (2021). Group Forecasts Massive Increase in Energy Storage by 2030. POWER Magazine. Available online: https://www.powermag.com/group-forecasts-massive-increase-in-energy-storage-by-2030/ (accessed on January 2025).

[44] Ambrose, J. (2021). Electric vehicles on world's roads expected to increase to 145m by 2030 | Electric, hybrid and low-emission cars. The Guardian. Available online: https://www.theguardian.com/environment/2021/apr/29/electric-vehicles-on-worlds-roads-expected-to-increase-to-145m-by-2030 (accessed on January 2025).

[45] Mörée, G., & Leijon, M. (2022). Overview of Hybrid Excitation in Electrical Machines. Energies, 15(19), 7254. doi:10.3390/en15197254.

[46] Alsop, T. (2022). 3D printing & additive manufacturing devices 2030. Statista. Available online: https://www.statista.com/statistics/1259618/3d-printing-and-additive-manufacturing-devices-worldwide/ (accessed on January 2025).

[47] Amelia H. (2021). Wohlers Report 2021: Weakened Growth for Additive Manufacturing. (2021). 3Dnatives. Available online: https://www.3dnatives.com/en/wohlers-report-2021-180320214/ (accessed on January 2025).

[48] Marković, M. P., Cingesar, I. K., Keran, L., Prlić, D., Grčić, I., & Vrsaljko, D. (2022). Thermal and Mechanical Characterization of the New Functional Composites Used for 3D Printing of Static Mixers. Materials, 15(19), 6713. doi:10.3390/ma15196713.

[49] BBC. (2019). Robots to replace up to 20 million factory jobs by 2030. BBC News. Available online: https://www.bbc.com/news/business-48760799 (accessed on January 2025).

[50] Krot, K., Iskierka, G., Poskart, B., & Gola, A. (2022). Predictive Monitoring System for Autonomous Mobile Robots Battery Management Using the Industrial Internet of Things Technology. Materials, 15(19), 6561. doi:10.3390/ma15196561.

[51] DiChristina, M., & Meyerson, B. S. (2017). Top 10 Emerging Technologies of 2017. Scientific American, 317(6), 28–39. doi:10.1038/scientificamerican1217-28.

[52] Duggal, N. (2023). Top 18 New Trends in Technology for 2023. Simplilearn. Available online: https://www.simplilearn.com/top-technology-trends-and-jobs-article (accessed on January 2025).

[53] Nguyen, T. (2023). 4 Emerging Technologies You Need to Know About. Gartner. Available online: https://www.gartner.com/en/articles/4-emerging-technologies-you-need-to-know-about (accessed on January 2025).

[54] Kemp, S. (2020). We are social, Digital 2020: 3.8 billion people use social media. We Are Social Ltd. Available online: https://wearesocial.com/uk/blog/2020/01/digital-2020-3-8-billion-people-use-social-media/ (accessed on January 2025).

[55] Gackenbach, J., & Bown, J. (Eds.). (2017). Boundaries of self and reality online: implications of digitally constructed realities. Academic Press, London, United Kingdom.

[56] Leiner, B. M., Cerf, V. G., Clark, D. D., Kahn, R. E., Kleinrock, L., Lynch, D. C., Postel, J., Roberts, L. G., & Wolff, S. (2009). A brief history of the internet. ACM SIGCOMM Computer Communication Review, 39(5), 22–31. doi:10.1145/1629607.1629613.

[57] Cooper, M., Dronsuth, R. W., Leitich, A. J., Lynk, J. C. N., Mikulski, J. J., Mitchell, J. F., Richardson, R. A., & Sangster, J. H. (1975). Radio telephone system. United States Patent No. US3906166A. Available online: https://patents.google.com/patent/US3906166A/en / (accessed on January 2025).

[58] Shao, G. (2019). The future of connectivity: Introducing Wi-Fi 6. The CNBC News. Available online: https://www.cnbc.com/2019/06/27/what-is-wi-fi-6.html (accessed on January 2025).

[59] Labiod, H., Afifi, H., & De Santis, C. (2007). Wi-Fi ™, Bluetooth ™, ZigBee ™ and WiMax ™. Springer Netherlands. doi:10.1007/978-1-4020-5397-9.

[60] Xu, X., Wei, Z., Ji, Q., Wang, C., & Gao, G. (2019). Global renewable energy development: Influencing factors, trend predictions and countermeasures. Resources Policy, 63, 101470. doi:10.1016/j.resourpol.2019.101470.

[61] Sørensen, B. (1991). A history of renewable energy technology. Energy Policy, 19(1), 8–12. doi:10.1016/0301-4215(91)90072-V.

[62] Sculpteo (2024). The State of 3D Printing. Discover the largest study of the Additive Manufacturing industry. Sculpteo. Available online: https://info.sculpteo.com/the-state-of-3d-printing-report (accessed on January 2025).

[63] Liang, K., Carmone, S., Brambilla, D., & Leroux, J. C. (2018). 3D printing of a wearable personalized oral delivery device: A first-in-human study. Science Advances, 4(5), 2544. doi:10.1126/sciadv.aat2544.

[64] Accenture. (2019). Technology Vision 2019. The post-digital era is upon us: Are you ready for what's next? Accenture. Available online: https://www.accenture.com/content/dam/accenture/final/a-com-migration/r3-additional-pages-1/pdf/pdf-94/accenture-techvision-2019-exec-summary.pdf (accessed on January 2025).

[65] Keiser, B. E., & Strange, E. (1985). Evolution of the Integrated Services Digital Network (ISDN). Digital Telephony and Network Integration. Springer Netherlands. doi:10.1007/978-94-015-7177-7_14.

[66] Zhang, Y. (2019). Research on key technologies of remote design of mechanical products based on artificial intelligence. Journal of Visual Communication and Image Representation, 60, 250–257. doi:10.1016/j.jvcir.2019.02.010.

[67] Colmerauer, A., & Roussel, P. (1996). The birth of Prolog. History of Programming Languages II, 331–367. doi:10.1145/234286.1057820.

[68] He, X., Ai, Q., Qiu, R. C., Huang, W., Piao, L., & Liu, H. (2017). A Big Data Architecture Design for Smart Grids Based on Random Matrix Theory. IEEE Transactions on Smart Grid, 8(2), 674–686. doi:10.1109/TSG.2015.2445828.

[69] Chen, S., Zhong, S., Yang, S., & Wang, X. (2016). A Multiantenna RFID Reader with Blind Adaptive Beamforming. IEEE Internet of Things Journal, 3(6), 986–996. doi:10.1109/JIOT.2016.2542242.

[70] Kaplan, E. D., & Hegarty, C. (2017). Understanding GPS/GNSS: principles and applications. Artech House, Massachusetts, United States.

[71] Chekov, A. (2019). The development of a new generation GPS system has been completed in the USA. Available online: https://iz.ru/927626/2019-10-01/v-ssha-zavershena-razrabotka-sistemy-gps-novogo-pokoleniia (accessed on January 2025).

[72] Musiał, M. (2019). Enchanting Robots: Intimacy, Magic, and Technology. Springer Nature Switzerland. doi:10.1007/978-3-030-12579-0.

[73] Yang, G. Z. (2017). Digital architecture and robotic construction. Science Robotics, 2(5), 3673. doi:10.1126/scirobotics.aan3673.

[74] McLaughlin, M. L. (1996). The art site on the World Wide Web. Journal of Computer-Mediated Communication, 1(4), JCMC146. doi:10.1111/j.1083-6101.1996.tb00175.x.

[75] Marinescu, D. C. (2013). Cloud computing: Theory and practice. Morgan Kaufmann, Massachusetts, United States.

[76] Duarte, F. (2023). Amount of Data Created Daily 2024. Exploding Topics is a Trademark of Semrush Inc. Available online: https://explodingtopics.com/blog/data-generated-per-day (accessed on January 2025).