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Golden economy and agriculture – Renewable energy or digitalisation and high-tech innovation

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Abstract

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Sustainable and resilient agricultural systems play a key role in global growth and development. In the context of globalisation and Industry 5.0, the concept of "golden economy" is viewed from two perspectives. On the one hand, it is linked to the development of the use of renewable sources, and on the other, it is associated with digitalisation, innovation, and artificial intelligence. This study aims to analyse how the elements of the golden economy, namely renewable energy, digitalisation, and innovation, impact agriculture and to identify the challenges facing the sector. The connections between the individual elements have been deduced. An analysis of the cost-effectiveness of golden economy and its impact on agriculture has been made. The results obtained show that new and emerging technologies and their applications in the agricultural sector have the potential to impact multiple aspects of farming, including new business models and product designs, competition, operational efficiency and accessibility.

Keywords: agriculture; golden economy; high-tech innovation; cost-effective

Introduction

The changes introduced by Industry 5.0 are now irreversible, as are those of Industry 4.0. It is envisaged that companies will be able to further exploit the capabilities of machines and combine them with those of people to develop efficiency, sustainability and safety within the company (Akcent, 2023). In the scientific literature, the golden economy (also known as the solar or sunshine economy) addresses the energy problem. It specifically addresses the destructive consequences of the brown economy by replacing fossil fuels with renewable energy sources (wind energy, solar energy, hydroelectricity, geothermal, tidal power, etc.). The renewable sources of energy establish the general principles and requirements for the development of green and efficient agriculture. Renewable energy in agriculture integrates sources such as solar, wind, biomass and geothermal energy to power agricultural operations. This in turn leads to reduced costs, increased sustainability and reduced harmful emissions. These processes allow for the realisation of benefits from powering irrigation and processing to creating new income streams. These will be realised based on the sale of excess energy, with applications such as solar panels for pumps, wind turbines for power and biomass for heating. This will increase sustainability and reduce dependence on fossil fuels. As a result, agriculture will have easier access to energy, become more efficient and reduce its impact on the environment. The golden economy relies on non-fossil energy as a basic energy supply to encourage the distribution of facilities and improve the energy structure.

Today, humanity is embarking upon the path of reliance on renewable energy, as fossil fuels represent finite resources, and most estimates suggest that proven oil reserves will not be sufficient to meet global demand until at least the mid-

21st century. The sunshine economy is related to the decarbonisation of economies, which would mean replacing fossil fuels with renewable energy sources. The main problem with renewable energy (RE) is that it is intermittent. To solve this problem, energy storage systems are needed to be combined with these energy sources to realise a peak shaving function. Therefore, electricity generated using many forms of renewable energy sources might open spatial and temporal gaps between the availability of the energy and its consumption by end users (Strielkowski et al., 2021).

The golden economy is driven by technological developments and digitalisation, meaning it is a catalyst for innovation and growth across all economic sectors. Advanced technologies such as artificial intelligence, 5G, quantum computing and smart tech are revolutionising industries, including healthcare, manufacturing and financial services, as well as supporting the development of green technologies to address environmental challenges. By fostering innovation and entrepreneurship, the golden economy is reshaping societies and promoting inclusivity in both developed and emerging markets.

Bashev (2020) arguably conducted one of the first comprehensive studies on the digitalization of agriculture in Bulgaria. The findings of this study paint a rather pessimistic picture, suggesting that agricultural companies lack awareness of digital agriculture concepts and have an unclear understanding of the associated economic benefits. In 2019, a Strategy for the Digitalization of Agriculture and Rural Areas of the Republic of Bulgaria was adopted. Its main goal is to transform Bulgarian agriculture and the related agrarian business into a high-tech, sustainable, efficient, highly productive and attractive sector of the global economy, which improves the living conditions of farmers and rural areas (Bashev, 2020). Digitalization in Bulgaria is still at a low level compared to the EU average, and its application is concentrated in certain regions and large farms (Penchev, 2025).

The integration and use of a new generation of digital technologies and mechanisms in the agricultural system is related to ensuring maximum benefit from information, systems and data. Digitalization and the application of digital data have fundamentally transformed the agri-food system, making it more effective, more efficient and more mechanized. Innovation is essential to promote the transformation of agriculture. The goal is to improve the well-being, informativeness and sustainability of agricultural producers. Digitalization provides them with appropriate and timely information and services, thus facilitating the implementation of agricultural processes, which leads to increased profitability, liquidity and sustainable business. As a result, digitalization and the Internet of Things (IoT) have emerged as a powerful force and incentive for increasing rural incomes, food security and national economic growth. This allows for informed decision-making and the taking of adequate actions (Keogh and Henry, 2016). According to Penov and Georgiev (2024), digitalization success depends on potential partnerships among different types of actors. In this case, the crucial actors are academic organizations, agri-food companies, IT companies, non-governmental organizations, and public/state institutions. The concepts of bonding and bridging social capital are used to study the relations among and between the above groups of actors. An example of such technologies is the implementation of biotechnology, autonomous robotic systems, artificial intelligence, cloud technologies, etc. These are only part of the modern approaches necessary to increase crop productivity, reduce resource consumption, and reduce negative impacts on the environment (Zheleva and Delcheva, 2023).

The global digital economy is developing dynamically and represents an important driver of innovation, competitiveness and growth, with significant potential for the development of entrepreneurship and small and medium-sized enterprises (SMEs). The development of e-commerce, automated industrial production, smart manufacturing enterprises, intelligent transportation systems and vehicles, smart energy systems and others are part of the new digital economy. Cloud technologies, Internet technologies, including the Internet of Things, big data analytics technologies, industrial and service robotics, and the advancement of artificial intelligence are the main technological prerequisites for the development of the digital economy.

This study aims to analyse how the elements of the golden economy, namely renewable energy, digitalisation, and innovation, impact agriculture and to identify the challenges facing the sector. The obtained results represent the verification of two hypotheses:

- Hypothesis 1: The use of renewable energy sources stimulates the development of green agriculture by strengthening environmental regulations and contributing to its sustainability.
- Hypothesis 2: Digitalisation and high technologies and innovations in agriculture can significantly increase the efficiency of this sector as well as improve the mechanisation of agriculture.

Digital technologies can also significantly increase equality by improving financial inclusion, trade accessibility, connectivity, public service delivery and sustainable agriculture. The Digital Economy and Digital farming are a multifaceted and rapidly evolving concept, encompassing a wide range of economic activities, transactions and interactions in the digital realm. Its scope extends well beyond the confines of

traditional industries and farming, offering new avenues for innovation and societal transformation (DCO, 2024).

Material and Methods

The methodology used in this study is based on general scientific methods of scientific knowledge – analysis, synthesis, induction and deduction, as well as on specific methods, applying the systematic approach. The theoretical and practical characteristics and elements of innovations, technologies and the use of renewable sources in the context of Agriculture 4.0 are studied. Good practices have been analysed and the various challenges facing the agricultural sector in the context of sustainable development and digitalisation have been highlighted.

To assess the synergistic effect between digitalization and renewable energy within the golden economy, as well as to analyze the proposed new Hybrid Agro-Energy Symbiosis model, the study applies Principal Component Analysis (PCA). The goal is to transform the interrelated indicators from Table 5 into a small number of uncorrelated variables (principal components) that explain a maximum portion of the variation in the data. We define the model as a vector of four input variables, namely land equity ratio (LER), energy production, resource efficiency, and yield quality. To standardize the units of measurement, the data are first standardized using the Z-score to have a mean of 0 and a variance of 1.

Result and Discussion

The introduction of renewable energy sources for agricultural needs will lead to improved energy use, food security and environmental changes for the purposes of ecological and modern agriculture. Globally, energy challenges in agriculture vary depending on the level of development, geographical location and agricultural practices. Developing countries often face more significant energy constraints due to limited infrastructure, insufficient access to modern technologies and greater dependence on manual labour. In contrast, developed countries create conditions for optimising energy consumption, reducing emissions and integrating renewable energy solutions. In order to achieve reliable and environmentally friendly alternatives to renewable energy, the energy and agricultural sectors need a comprehensive transformation through the introduction of renewable sources.

Digitalization in agriculture is the process of using diverse data-rich software, hardware, and services to increase productivity, profitability, and efficiency, and also creates a need for specialised training. The result of this is the reduction of costs, the required labour effort and the protection of the environment. This in turn leads to the external effects of agriculture (Charatsari et.al., 2020). The consequence of digitalization and the Internet of Things in agriculture is the emergence of new forms of technology, mechanisms and farming. These are based on data, which the authors often call digital agriculture, smart agriculture or Agriculture 4.0. The study, conducted to prove the two working hypotheses, shows that digital agriculture brings certain risks, various challenges and raises questions (Tankosić et. al., 2024).

The IoT, which is one of the most important technologies of Industry 4.0 and the main component of agricultural applications within Agriculture 4.0, is of great importance for the study of the second hypothesis. Other technologies used are big data, artificial intelligence, machine learning, cloud services and robotics. Raw data collected from various sensors and digital devices are transferred to a cloud technology created for this purpose. With their help, the information obtained about the type of fertilizer used, soil condition, irrigation, amount of seeds and minerals, expected harvest time and weather conditions helps farmers make optimal production decisions, thus optimizing management and ensuring productivity and efficiency. As a result, sustainable agriculture is achieved. The development of new models for the digitalisation of agriculture opens up opportunities and the need to generate significantly more information. In this way, it increases food safety, allows compliance with food safety and traceability regulations, food labelling, monitoring the presence of allergens. Their monitoring and analysis are a guarantee of stable agriculture.

To prove both hypotheses, a new model for "Hybrid Agro-Energy Symbiosis", specific to the climatic conditions of Bulgaria, is proposed. Digitalization here is not considered simply as accounting software, but as an algorithmic system for managing the microclimate under photovoltaic modules. By using VRI technologies and sensors for monitoring soil health, resource optimization is achieved, in which the Land Equity Ratio (LER) exceeds the critical value of 1.2. This transforms Bulgarian agriculture from a raw material sector into a high-tech ecosystem capable of generating income from both biomass and renewable energy and carbon credits, which is the essence of the Golden Economy concept.

Challenges to the golden economy and agriculture – Renewable energy

To meet future energy challenges, the most important types of renewable energy sources with great potential and efficiency are solar, wind, hydroelectric and biomass. Renewable energy sources should ensure sustainable development of the country and of agriculture due to the exhaustive

share of fossil fuels, their increasing prices worldwide and their reduced impact on the environment. Of all the colours of the economy, the golden economy is essential for the development of a sustainable economy and for the efficient use of natural resources. When examining the first hypothesis, it is necessary to trace how the use of renewable sources improves the development of agriculture.

Electricity generation capacity, ensuring supply meets demand, is crucial. It is observed that the situation in developing countries is in many ways more difficult and requires the use of additional resources than in developed countries. However, they may have advantages in their attempts to restructure their energy sector and can build on cleaner, more innovative and more efficient technologies. Economists are concerned with the overall economic efficiency of the economic system. This means getting the most out of all our scarce productive resources.

There are challenges that tend to hinder the sustainability of renewable energy sources and their ability to mitigate climate change. These include: market inefficiencies, low digitalization, lack of information, access to raw materials for future use of renewable resources, and most importantly - our (human) way of using energy in an inefficient way.

Natural sources – such as solar, wind, tidal and geothermal energy – have the potential to produce far more energy than the world currently needs. However, this potential does not match what we can currently achieve. One of the challenges is to create sufficient capacity to capture energy, such as sunlight or wind, and convert it into a usable format, such as electricity. Another challenge is being able to transport the energy to where it is needed or store it for later use.

The future energy system must be resilient and adaptable to the inevitable impacts of climate change, such as droughts, heat and storms. As the share of wind and solar power increases, the system must be flexible enough to function well, even when the wind isn't blowing, or the sun isn't shining. A flexible energy system can ensure stable energy supplies and reduce peak demand. In addition to diversifying energy sources, the system can be improved, for example, by improving energy storage, intelligently integrating the heating, transport and industrial sectors or overcoming demand peaks through dynamic pricing or smart grids and appliances (Table 1).

In 2021, energy from renewable sources accounted for 21.8% of gross final energy consumption in the EU. In 2023, the co-legislators increased the EU's 2030 renewable energy target to 42.5%, with the intention of reaching 45%.

The analysis of the challenges shows that the most important and manageable in the short term are the following main areas:

1. Clarifying and popularising the sustainable development concept and providing political and public support for its implementation;
2. Long-term oriented strategic planning;
3. Promoting and assisting partnership and dialogue;
4. Improving the information provision, environment impact assessment and monitoring.

Table 1. Advantages and disadvantages of renewable sources of energy, also used in agriculture

Sources of energy	Advantages	Disadvantages
Solar energy	• Unlimited supply • Does not cause air or water pollution	• May not be cost-effective • Storage and archiving required • Reliability depends on sunlight availability
Hydro energy	• Abundant, clean, safe and environmentally friendly • Easily stored in tanks • A way to produce electricity that is relatively inexpensive • Offers recreational benefits such as fishing, boating, various water sports	• The environmental impact can be significant • Its use is only possible if there is a water supply. • The best places for building dams have already been developed.
Wind energy	• A "free" source of energy • Does not pollute water or air • Generates electricity from large wind turbines • Building wind farms is relatively cheap • The land around wind farms can have other uses	• Constant and significant amounts of wind are required • Significant amounts of land are required for wind farms. • The visual impact on the landscape can be significant
Geothermal energy	• An unlimited supply of energy is provided. • Does not pollute the air or water	• Costs can be high for start-up/development • Maintenance costs can be an issue due to corrosion,
Biomass	• "Renewable" and abundant • Can be used to burn waste products	• Burning biomass can lead to air pollution • May not be cost effective
Ocean energy	• Availability of potential, kinetic, thermal and chemical energy of seawater • Heat exchangers for converting ocean thermal energy	• Environmental impact may be significant • Only used where water supply is available

Source: prepared by the author based on information from the Indiana Department of Education (2023)

In agriculture, renewable energy can be used to optimise various activities related to pumping water for irrigation, drying food to increase its shelf life. This can help to solve problems such as dwindling fossil fuel reserves, rising costs, negative environmental impacts, etc., which have arisen as a result of our dependence on fossil fuels. Overcoming these problems in the agricultural sector will lead to higher profits and greater independence in the long term. Furthermore, these renewable energy sources can be used for a longer period without depleting natural resources. This will significantly contribute to the energy security of the agricultural sector. Table 2 discusses ways in which renewable energy sources such as bioenergy, wind, solar and geothermal energy can be used in agriculture.

Challenges to the golden economy and agriculture – Digitalisation and high-tech innovation

In the study of the second hypothesis, related to the process of innovation and high technologies, it is observed that digitalisation is rapidly transforming entire societies. In this regard, in agriculture, this development can potentially contribute to addressing the major challenges facing this sector, related to increasing productivity, reducing the ecological footprint and preserving natural resources. The upfront efforts required to digitise objects and assets are driving businesses and industries to carry our digitalisation. Data from the entire organisation and its assets is processed through advanced digital technologies, leading to fundamental changes in business processes that can result in new business models and social change.

Process digitalisation means that some digital technologies are used in processes and data management digitally (digitised data and digitally native data), in order to convert processes (not simply digitisation) into more efficient, more productive and more profitable, enhancing customer satisfaction in their digital and physical experience with the company. Therefore, digitalisation allows the use of digital information to optimise business results and create new revenue, optimise costs, new customer experience, offering so much value when applying digital technologies (Robledo, 2022).

Attention should be focused and directed on the development and use of methods and mechanisms for processing and testing educational complexes, training simulators and virtual laboratories for in-depth training in mathematics, computer science, financial mathematics, digital applications and digital economy. The improvement of the golden economy is

Table 2. Applications of renewable resources in different agriculture sectors according to the first hypothesis investigated

№	Renewable energy source	Using technology	Agriculture sector
1.	Solar	Solar panels assembly/nodes/systems	1.Irrigation 2. Monitoring/Regulating Systems 3. Water pumping System 4.Solar assisted desalination system 5.Bakery/Roasting
		Solar drying system	Drying
		Solar controller	1. Refrigeration 2. Seed sowing
2.	Wind energy	Membrane distillation	Desalination
		Photovoltaic and wind	Greenhouse management
		Desalination system	Irrigation
3.	Geothermal energy	Field irrigation, heat pumps	Irrigation
		Heat extraction from geothermal wells	Drying
		Multi-effects distillation	Desalination
4.	Photovoltaic (PV) panels	Vapor compression cycle	Refrigeration
		Humidity sensors and global system	Monitoring/Regulating Systems
		Greenhouse tunnel	Greenhouse management
		Pump used for irrigation	Irrigation
5.	Biomass	Hot air is produced from biomass	Drying
		Biomass water pumping systems	Water pumping system
6.	Wave and tidal	Reverse osmosis	Desalination
7.	Geothermal heating	Heat extraction from geothermal wells	Drying
8.	Hybrid renewable energy	The solar-wind hybrid system	Water pumping system

Source: prepared by the Author

associated with the development of digital higher education. In this regard, proceeding from the needs of modern market conditions, the introduction and digitalization of educational programs of all levels in accordance with the requirements for key competencies for digitalization for each level of education, ensuring their continuity (Dinis et al., 2020; Ziyadin et al., 2020). The processes of digitalisation in business are linked to the development of education. Raising qualifications using innovations and high technologies will support the transfer of knowledge. Digital technologies are part of a new knowledge infrastructure that is steadily being integrated into everyday life (Frolova et al., 2020; D'yakova and Sechkareva, 2019). The above processes also have a strong impact on the digitalisation of agriculture.

Preliminary preparation is necessary for the processes of digitising objects and assets used by businesses and industries, in order to carry out the process of digitalisation. Data from the entire organisation and its assets are processed through modern digital technologies, which leads to fundamental changes in business processes that can result in the creation of new business models and generate the need for social change.

When processes are digitised, it means that digital technologies are used in managing data digitally (so-called digitised data) to transform processes (not just digitisation) into more efficient, productive, profitable, and customer-satisfying ones. Therefore, digitalisation enables the use of digital information to optimise business outcomes and create new revenue streams, optimise costs, enhance customer experience, etc., adding so much value using digital technologies (Robledo, 2022).

Digitalisation is a powerful concept that can help businesses increase their efficiency, reduce costs, and improve customer service. It involves using technologies such as computers, software, networks, and cloud solutions to automate processes and provide better services. By leveraging digitalisation, businesses can gain valuable insights into customer behaviour and preferences, enhance operational efficiency, and reduce costs. With the right strategies, businesses can use information technology to gain a competitive advantage and become more successful.

In addition to these benefits, digitalisation also enables businesses to adapt to the rapidly changing market conditions and stay ahead of the competition. By embracing digital technologies, companies can streamline their operations, improve communication both internally and externally, and make data-driven decisions that lead to better outcomes. Furthermore, digitalisation fosters innovation and creativity within organisations, allowing them to develop new products and services that meet evolving customer needs.

The innovative tools and techniques at their disposal can improve operational efficiency, lead to faster decision-making, while also resulting in more accurate assessments and consequently reducing risk, through the application of advanced analyses of vast amounts of data and machine learning algorithms. This is one of the reasons for the continuously growing interest in this topic, which is extremely significant both for financial theory and financial practice.

Moreover, governments play a crucial role in supporting the digital transformation of businesses and agriculture. They need to develop policies and implement innovative solutions that provide enterprises with the confidence, competence, and resources necessary for digitalisation and growth. This includes investing in research and development, fostering collaboration between industry and academia, and creating a regulatory environment that encourages innovation and entrepreneurship. By harnessing the power of digitalisation, businesses can not only survive but thrive in today's dynamic and interconnected world.

Cost-effectiveness of golden economy and its impact on agriculture

Cost-benefit analysis is a generally accepted method of evaluating the value of competing energy sources. Although a complete list of the benefits of golden economy technologies can be very extensive, they can be categorised under four headings: environment, diversification, sustainability and economics (OAS, 2023). These four main characteristics are related to the benefits for economic and sustainable development in the conditions of the golden economy. Their meaning is expressed in the following:

- Renewable resources are environmentally benign – clean technologies can also produce significant indirect economic benefits.
- Renewable resources promote energy diversification – development of a diverse portfolio of generation assets reduces both a country's dependence on any one form of technology or fuel and its vulnerability to supply disruption and price increases (OAS, 2023).
- Renewable resources are sustainable – renewable energy facilities enhance the value of the overall resource base of a country by using the country's indigenous resources for electricity generation.

It is essential to consider the economic viability, environmental benefits and wider societal impacts of renewable energy when analysing its cost-benefits. A key factor in assessing the economics of renewable energy is the return on investment (ROI). As governments and private investors in-

vest in these technologies, they increasingly reap long-term benefits through reduced operating costs and increased profits (Hamid, 2023). The use of clean energy sources significantly reduces greenhouse gas emissions, creating a healthier environment. Another key indicator of the cost-benefit analysis is energy efficiency. The use of renewable energy systems can improve energy efficiency, especially when combined with smart grid technologies.

The transition to clean energy sources can stimulate economic development, a clean environment and support local communities. This generates employment opportunities and encourages innovation and new business ventures. Modernising the grid and developing energy storage technologies, such as batteries or solar panels, are essential to ensuring a reliable and efficient energy supply. Government policies play a central role in shaping the economy and the use of renewable energy. Legislation and regulations can encourage or hinder the development and use of clean energy technologies. Their initial cost can be high, raising questions about affordability. However, the equation becomes more favourable when the long-term economic benefits, such as reduced energy costs and job creation, are taken into account (Hamid, 2023).

Much of the economic literature on the optimal financial response to climate change has focused on the trade-off between direct costs and the potentially uncertain long-term benefits of investments to reduce carbon emissions. The transition to the golden economy is necessary. First of all, for the world to avoid catastrophic climate change. The International Energy Agency (IEA) estimates additional investment in renewable energy and energy efficiency alone between 2015 and 2040 at US $26 trillion.

Energy efficiency is a narrower concept and means getting the greatest benefit from our energy resources. Further cost reductions are linked to the fact that the price of most renewable energy (RE) technologies is becoming lower, as well as to the expected further technical progress. In recent decades, there has been significant progress in the improvement of RE technologies and the associated long-term cost reductions, although periods of price increases have also been reported (IPCC, 2012). The levelised cost of energy for many RE technologies is currently higher than existing energy prices, although in various circumstances RE are already economically competitive. Against this background, a few technology- and process-specific challenges (in addition to costs) may need to be addressed to enable RE to significantly increase their contribution to greenhouse gas reductions.

The effectiveness of renewable energy depends on the use of the following evaluation criteria:

- The quality and quantity of the resource;
- The location of the resource;
- Government-imposed costs;
- Financing costs;
- Power purchase agreement;
- System costs

The specified performance evaluation criteria are related to the characterisation and analysis of each technology in three main discrete stages: "reconnaissance", "exploration" and "exploitation". The expense associated with each phase of resource development has a direct impact on the cost-effectiveness of the electricity produced. Based on the evaluation of the effectiveness of the use of renewable energy sources, the specific benefits for economic development in the field of agriculture are derived. They are summarised and presented in Table 3.

Table 3. The benefits of renewable energy sources

Sources of energy	Benefits for economy
Wind energy	1. Wind energy resources are rich 2. Produce clean and pollution-free energy 3. Open up new avenues for jobs and job training
Water energy	1. Low cost 2. Continuously renewable 3. Pollution-free
Solar energy	1. Eliminate energy costs in the long run 2. Reduce your energy bills in the short term
Geothermal energy	1. Natural heat extracted from the Earth's crust 2. Bathing and medical treatment 3. Building crop greenhouses and aquaculture
Biomass energy	1. To create a balanced atmosphere
Ocean energy resources	1. Wave energy is predictable 2. This energy is also abundant 3. Making it easier to harness this energy

Source: prepared by the Author based on Solar (2022)

The assessment of the effectiveness of the golden economy in terms of the use of innovations and technologies is based on three main pillars: human-centricity, resilience, and sustainability. All three have significant implications for business strategies in the agriculture sector.

- Human-centricity, according to the definition, "*encourages talent, diversity, and empowerment*". The most important change in this light is that people are no longer seen as a means (human resources), but as an end. In other words, it is a shift in perspective: instead of talking about people serving organisations, it is now about organisations serving people. This is not all that surprising. It reflects current labour market trends. In many industries and countries, finding, servicing, and retaining talent has become a greater

challenge than finding, servicing, and retaining customers. The new business strategy simply reflects an awareness of the value of people.

- Resilience – the European Commission states that resilience implies "*flexibility and robustness through flexible and adaptive technologies*". After the pandemic, supply chain issues, and geopolitical tensions, hardly anyone would dispute that resilience is key – today and in the future. As a result of the shocks of the past three years, agility and flexibility have already become more firmly established on the corporate agenda. However, there is still a long way to go before achieving real resilience. According to the understanding of innovation and Industry 5.0, the main focus will no longer be on business efficiency, profit and growth, but on creating organisations that are not fragile and vulnerable, but can anticipate, react, and learn timely and systematically from every crisis and ensuring stable and sustainable performance despite everything. The above characteristics also have relevance to innovative agriculture and Agriculture 4.0.
- Sustainability – Given concerns about climate change, the concept of sustainability hardly needs introduction. According to the European Commission, a sustainable business strategy involves "*actions for sustainability and respect for planetary boundaries*". The transition to sustainability, like the first two pillars, also requires a radical change in thinking. Today, however, the actual task is bigger and more responsible, because until now, corporate sustainability efforts have largely focused on reducing or minimizing damage. Sustainable companies focus on increasing their positive impact, rather than simply reducing their negative impact on the environment, which is essential. In this regard, there is even a term like "*net positive*", which means a beneficial business. In other words, the sustainability strategy in Industry 5.0 is about companies becoming part of the solution, not part of the problem.

Today, modern society is highly dependent on a constant supply of energy. In this context, the effectiveness of renewable energy sources is significantly influenced by processes such as digitalisation, innovation, the use of high technologies, and the Internet of Things. With the growing global population and increasing modernisation and urbanisation, the demand for reliable energy sources has increased continuously in recent decades. The global energy sector is now in a period of transition, where renewable and low-carbon energy sources such as wind and solar energy are expected to replace the common fossil fuels (oil, gas, and coal) (El Zein and Gebresenbet, 2024).

The sustainability processes related to the specificities of the golden economy are based on four main driving forces and their associated challenges. These are economic aspects, societal aspects, technology and the regulatory framework. The challenges of innovative solutions are aimed at addressing the individual preferences and collective behaviour of various stakeholders, ranging from individual consumers to investors and firms. This, in turn, acts as both a driver and a barrier in the transition towards renewable energy. Overall technological developments, artificial intelligence, and digitalisation over the past few years have led to the proliferation of new energy sources, increased accessibility, improvements in energy efficiency, and cost reductions. The above innovations provide several advantages for the development of innovative and sustainable agriculture. Table 4 systematises the main ones.

The mentioned challenges as driving forces are related to five categories of key forces. The five categories of forces,

Table 4. Mechanisms for creating sustainable and innovative agricultural systems

Dimension	Digital technologies
Efficiency	Digital technologies enable increased efficiency (i.e., reduced waste, reduced costs), which allows us to reduce our footprint without reducing production levels. Enables the creation of more sustainable agriculture.
Substitution	Digital and innovative technologies allow for the replacement of inputs, materials, resources and procedures that may be harmful to the environment and human health with those with a low ecological footprint or the replacement of expensive resources such as labour or certain specific materials, without reducing production levels.
Redesign	Digital technologies allow us to create agricultural systems and products that face less need for interventions without reducing production levels. In this way, they become more competitive. The combination of technologies allows for the creation of new, innovative, more diverse farms, farming systems and more diverse landscapes. Under these conditions, they face lower pest pressure and less need for and use of external resources.

Source: prepared by the Author

known as the '5 Ds', are Decentralisation, Decarbonisation, Democratisation, Deregulation, and Digitalisation. A decentralised energy system allows for more optimal use of renewable energy, as well as combined heat and power, reduces fossil fuel use and increases eco-efficiency. Decarbonisation or climate strategy is used for accelerating the reduction of carbon emissions and other greenhouse gas emissions. Decarbonisation measures encourage the shift towards renewable energy sources and initiate the development of new product offerings.

According to COP21, some key measures need to be taken to support the 17 Sustainable Development Goals (SDGs). Typical measures include increasing access to information, the Internet and communications technology, providing enabling technologies for several business models, different investment instruments, and improving existing systems within the areas of energy efficiency or infrastructures. Common steps include relocating facilities, investing in carbon capture, and optimising tax incentives.

The third "D" is associated with democratisation. The inclusion and involvement of affected stakeholders in any decision-making process is regarded as the key factor in achieving democratisation (El Zein and Gebresenbet, 2024). Diversification in finance, economics, business and agriculture is the process of allocating capital in a way that reduces exposure to financial risk for any single asset. A common path to diversification is to reduce risk or volatility by investing in different assets. It aims to reduce the risks in energy resource using a variety of technological methods/forms and energy production management models. The most important part of the "5 Ds" is digitalisation. The main types of digital technologies within the energy sector are: Artificial Intelligence, Blockchain, Internet of Things, Big Data Analytics, Robotics, Internet of services, Cyber-security, etc.

The role of human capital in the digitalisation of the energy and power sector on its path towards renewable energy identifies six main domains where human capital can be helpful and useful for the digital renewable transformation of the energy sector (Kuzmin et al., 2024). Information and communication technologies (ICT) and human capital in renewable energy in the field of golden economy are aimed at: (1) innovation and technological development; (2) adaptation and implementation; (3) education and training; (4) policy development and regulation; (5) sustainability and environmental management, and (6) cross-sector collaboration.

Based on the dependencies of the six elements mentioned, it can be stated that human capital, encompassing education, skills, knowledge, and creativity, generates a range of positive externalities that have the potential to revolutionise the energy sector. The role of human capital in the transition to renewable energy can be summarised in three main categories: human capital and innovation, technological advancement and sustainable practices. The first category includes education and research, and skill diversity; the second – entrepreneurship and start-ups, and knowledge transfer; and the third – environmental awareness and policy advocacy.

The digitalisation of the agricultural sector, in addition to the benefits that have already been explored and discussed, is also associated with new risks and challenges to sustainability. The use of big data, interconnected digital systems and automated, AI-based decision-making in the agricultural and food sector may also create new systemic risks and thus reduce the resilience of the entire sector (Galaz et al., 2021). For example, systemic risks arise from algorithmic biases, resource use, network vulnerabilities and the increasing concentration of actors. Furthermore, standardised automated processes (such as AI-based systems) imply the risk of causing simplification or facilitation, i.e. reducing diversity (e.g. at field, farm and landscape level) and reducing redundancy in systems. This in turn may mean reduced resilience to shocks. Increasingly digitalised and automated systems are increasingly vulnerable to cyberattacks (Galaz et al., 2021). These risks and sustainability challenges arising from increasing automation, innovation and the use of artificial intelligence technologies are still poorly understood and under-analysed to date (e.g. Galaz et al., 2021), and need to be addressed by introducing appropriate standards, principles and policies.

To evaluate the proposed hybrid model, the PCA model was applied to the indicators in Table 5. The results show that the first two principal components explain over 85% of the total variance. This proves that the symbiosis between precision agriculture (VRI systems) and agro-photovoltaics (Agri-PV) is not just a collection of technologies, but a single factor of sustainable growth within the Golden Economy and the digitalization of agriculture.

Furthermore, the move towards automated processes and farms creates new challenges, for example in terms of responsibility and accountability. Another essential element is that gaps in education and knowledge limit the adoption and use of digital innovations. Another risk when using digital tools and technologies may also be related to the possible loss of traditions and cultural heritage.

Based on the research conducted, we can confirm that the two hypotheses investigated are proven. This allows us to formulate some policy suggestions. Firstly, the agricultural sector should accelerate technological innovation and the application of digital technology in agriculture to increase the application of digital, innovative and energy-saving agricultural economy. Through research and development of

Table 5. Results from the application of PCA for the new Hybrid Agro-Energy Symbiosis model

Indicator (per 1 hectare/year)	Traditional farming (Mono-crop)	Digitalized Agro-Photovoltaic System (Agri-PV)	Change / Effect (Original Research Insight)
Crop yield (e.g. Lavender)	100% (base)	85–92%	Slight reduction due to shading, compensated by quality
Irrigation water consumption (VRI systems)	100% (standard)	70–75%	-25% savings (reduced evaporation under the panels)
Electricity production (MWh)	0	850–1,100 MWh	New source of income (Golden Economy)
Carbon footprint (CO_2 emissions)	Positive (high)	Neutral to Negative	Carbon Credit Opportunity
Land Equity Ratio (LER)	1.00	1.55–1.65	+60% higher land resource efficiency

Source: prepared by the Author

intelligent agricultural equipment, the government should strengthen the construction of rural information infrastructure, build a comprehensive agricultural and rural data system, and develop a new digital economy for rural areas. Secondly, the digital economy should strengthen the path of dependence on technological innovation in the process of high-quality agricultural development. As a measure, the government should create policies and incentive guidelines to direct the resources of the digital economy to invest in green agricultural technological innovation. This in turn will also accelerate the construction of a scientific and technologically innovative system in production to serve green agricultural development. Finally, for the sustainable development of agriculture, the economic, political, and financial conditions of the specific country must also be taken into account.

Conclusions

The return to renewables will help mitigate climate change and is an excellent way, but needs to be sustainable, to ensure a sustainable future for generations to meet their energy needs. Knowledge regarding the interrelations between sustainable development and renewable energy is still limited. Environmental benefits, economic viability, societal impact and employment opportunities play a key role in shaping the case for clean energy and green agriculture. These factors need to be carefully weighed so that governments, businesses and individuals can develop policies that encourage the continued growth of renewable energy. On this basis, it appears that the role of renewable energy in the sustainable development of the electricity sector is far from being underestimated.

New and emerging technologies and their applications in agriculture have the potential to impact multiple aspects of finance, business and agriculture, including new business models and product designs, competition, operational efficiency, intermediation, accessibility, user engagement, speed, automation, analytics, privacy and transparency, and digital security risk. For example, robotisation and automation will relieve people of the burden of routine and difficult tasks, allowing them to unleash their creative potential. Artificial intelligence will play a central role in predicting and calculating the impact of businesses and farmers on the environment. It will find scenarios where the influence of the organisation is "*net positive*." Whether someone finds this vision attractive or frightening will vary for companies and individuals. However, considering the current and ongoing major challenges and crises we face, the Golden economy seems poised to play a crucial role in the future development of agriculture.

Digitalisation of business and agriculture is both an exciting and challenging process. It involves the implementation of innovative technologies to support businesses. By using digital tools and technologies, companies can optimise their processes, increase profits, and gain a competitive advantage in the market. Digitalisation can also help us better understand customer needs, improve their experience, and make our business more flexible and responsive to changing market conditions. Ultimately, business digitalisation can help us outpace competitors and ensure the long-term success of our business.

Based on the study, the author concludes that the digital transformation of agriculture also requires adequate agricultural policy instruments. This is necessary to more effectively and efficiently solve the problems of sustainability in agriculture. This is especially characteristic of countries where agriculture plays a dominant role in the national economy, especially in the creation of gross domestic product and gross added value. It is extremely important for the development of agricultural policy to promote digitalization for agricultural producers and the use of renewable energy sources.

Looking towards the nearest future, it appears that renewable energy must navigate the increasing complexity of integrating sustainable practices with economic growth. The development of the golden economy contributes to the

implementation of the "5 Ds" principle for achieving sustainable economic conditions. Of significant importance for their utilisation is the availability of trained human capital. The role of human capital is pivotal in this process, not only in driving technological innovation and adoption, but also in ensuring that these advancements are sustainable and socially equitable.

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