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# Evolution of Business Continuity Management Strategies Amid Energy Crises: Emerging Trends in Energy Resilience Within Industry 4.0

Igor Lavrnić[1], Milivoje Jovanović[1], Minja Marinović[2*], Dejan Viduka[3]

[1] Department of Mechanical Engineering, Academy of Applied Studies Kosovo and Metohija, 38218 Leposavić, Serbia
[2] Department of Operations Research and Statistics, Faculty of Organizational Sciences, University of Belgrade, 11000 Belgrade, Serbia
[3] Department of Informatics, Faculty of Applied Management, Economics, and Finance, University Business Academy, 11000 Belgrade, Serbia

[*] Correspondence: Minja Marinović (minja.marinovic@fon.bg.ac.rs)

**Received:** 07-08-2024 **Revised:** 09-10-2024 **Accepted:** 09-18-2024

**Citation:** Lavrnić, I., Jovanović, M., Marinović, M., & Viduka, D. (2024). Evolution of business continuity management strategies amid energy crises: Emerging trends in energy resilience within industry 4.0. *Oppor Chall. Sustain.*, *3*(3), 168-176. https://doi.org/10.56578/ocs030303.



**Abstract:** The rise of advanced digital technologies (ADT) within Industry 4.0 has transformed modern industrial operations, with select industry leaders emerging as pioneers in the integration of these technologies. This has positioned them as benchmarks for companies with limited digital capabilities. The vulnerabilities of Industry 4.0 to external disruptions, including natural disasters such as the earthquakes in Japan and Turkey, the COVID-19 pandemic, and especially the ongoing energy crises, exemplified by the war in Ukraine and sanctions on the Russian Federation, have necessitated a shift in business continuity management (BCM) strategies. Traditionally focused on safeguarding information technologies, BCM now places greater emphasis on ensuring energy independence and reducing reliance on state-controlled critical infrastructure. In response to these risks, enterprises are increasingly adopting resilient production models designed to restore functionality after cyberattacks, solar flares, extended power outages, and internet disruptions. The journey toward energy independence spans from initial recognition of the need for action to the implementation of robust solutions, such as Faraday cages for server protection and off-grid energy systems. While rare a decade ago, energy-independent enterprises are becoming more common, as illustrated by the copper smelter in Sevojno, a pioneering example. The acceleration of energy independence among companies has been driven by a series of crises, prompting significant BCM advancements. Early responses to these threats primarily focused on information technology (IT) disaster management methodologies, but Industry 4.0 discussions have evolved toward risk-resilient production systems. This study explores theoretical approaches to enhancing enterprise resilience to modern energy challenges, offering insight into emerging strategies aimed at safeguarding continuity in an increasingly volatile global landscape.

**Keywords:** Business continuity; Industry 4.0; Energy independence of enterprises; Energy-independent communities

## 1. Introduction

There has been an obvious shift in the scientific community's focus toward the scenario of an energy collapse. Pre-crisis business continuity as a scientific field does not consider the possibility of a prolonged collapse of critical infrastructures, resulting in a cessation of electricity supply and loss of internet connections. After the COVID-19 pandemic and the energy crisis due to the war in Ukraine, things have changed significantly. New books have emerged in this field with titles of a new approach to business continuity doctrine. Many members of the scientific community are expanding the scientific field from IT to the continuity of enterprise operations, and significant investments are being made in companies' energy independence through their own production from renewable energy sources (RES). Energy independence refers to self-sufficiency in energy resources, energy supply, and/or energy production by the energy sector.

Moreover, being deeply aware of the danger of internet connection collapse, Industry 4.0 has turned to a new type of system maintenance called "Predictive Maintenance 4.0," which relies on artificial intelligence (AI) for continuous system monitoring during production to detect causes and anomalies in equipment operation and the possibility of system repair without connectivity to equipment manufacturer monitoring centers. It has become evident that instead of a generalized statement of the need for independence in supply and sales chains, it is necessary to act pragmatically and enable the enterprises to function in the event of a collapse of critical infrastructures.

The scale of the energy market disruptions that began in early 2020 and their role in the ongoing crisis are evident. In the initial months of the COVID-19 outbreak, fuel prices plummeted sharply, accompanied by a significant reduction in global energy consumption. Following this downturn, energy prices surged rapidly due to an unexpectedly fast economic recovery worldwide, prolonged colder-than-normal winters in the northern hemisphere, and slower-than-anticipated supply growth (Alvarez & Molnar, 2021). In particular, natural gas prices rose dramatically, reaching unprecedented levels in Europe and Asia. The effects of this surge also spread to coal markets. Indeed, the extremely high gas prices encouraged several markets, including those in the United States, Europe, and Asia, to increase their reliance on coal as an alternative to natural gas for energy production. As coal demand surged due to increased usage in power plants, coal prices reached their highest point since 2001 (Pescatori et al., 2021).

Energy security has once again become a central topic due to disruptions in energy markets. Over time, both policymakers and analysts have attempted to clarify this concept and its implications. According to the European Commission, energy security entails the ability to meet future basic energy requirements, either through sufficient domestic resources exploited under economically feasible conditions by maintaining strategic reserves or by accessing stable external sources to supplement, when necessary, strategic stockpiles (Barton, 2004). Long-term energy security involves timely investments to ensure energy availability that aligns with economic growth and environmental considerations, while short-term energy security focuses on the energy system's capacity to respond promptly to unexpected shifts in supply and demand.

In 2019, the World Bank Group halted its investments in oil and gas production. Additionally, the net-zero roadmap of the International Energy Agency (IEA) advocates for "no further investments in new fossil fuel supply projects or final investment decisions on new coal-fired power plants." These policies can exert pressure on developing nations, particularly in Africa, to transition to cleaner energy sources at the same pace as developed countries, despite their comparatively low contributions to global greenhouse gas emissions. Moreover, many developing regions still face a shortage of renewable infrastructure, making natural gas a critical transitional fuel as they build the capacity required for energy transition (International Energy Agency, 2011).

Thus, as gas shortages now pose a threat to the energy security of both developed and developing nations, many countries appear to be returning to the very energy sources—coal and oil—they aim to phase out. This reversal played a part in the 2021 energy crisis when the surge in energy demand, following the reopening of major economies, coincided with ongoing shortages in oil and natural gas supplies due to the 2020 demand collapse (Nagle & Temaj, 2021). This shift seems to contradict global efforts toward energy transition and climate initiatives in accordance with a review of commodity markets issued by the World Bank. The current energy crisis, therefore, exposes the vulnerability of climate initiatives in the face of sudden spikes in energy prices (Nagle & Temaj, 2021).

## 2. Increased Risks of Natural Disasters

According to the *Sendai Framework for Disaster Risk Reduction 2015-2030* adopted at the Third UN World Conference in Sendai, Japan, 2015, there has been a noticeable increase in the risk of natural disasters threatening the normal economic operation of any country. It is evident that there has been a global increase in awareness of the dangers posed by natural disasters to the normal functioning of the economy and critical infrastructure, which are prerequisites for normal life (United Nations Office for Disaster Risk Reduction (UNISDR), 2015).

By its most commonly used definition in scientific circles, disasters are extreme events in a particular time and space, in which the society or a part of society suffers damage and social disruption, thus compromising all or some basic societal values (Mavrodieva et al., 2019). Natural disasters can be observed as follows:

- Lithospheric disasters: avalanches and landslides, earthquakes, volcanic eruptions, and tsunamis;
- Hydrospheric disasters: floods, flash floods, and avalanches;
- Atmospheric disasters: stormy-hail phenomena, droughts, and extremely low and high temperatures;
- Biospheric disasters: epidemics, epizootics, epiphytotic, and forest fires.

Events such as earthquakes, tsunamis, volcanic eruptions, hurricanes, floods, and landslides are considered direct causes of natural disasters in the last decade (Mavrodieva et al., 2019).

In 2023, a total of 399 natural hazard-related disasters were documented in the Emergency Events Database (EM-DAT). These incidents led to 86,473 deaths and impacted 93.1 million individuals globally. The economic losses were estimated at US$202.7 billion. The earthquake that struck Turkey and the Syrian Arab Republic in 2023 was the deadliest and most economically damaging disaster of the year, causing 56,683 fatalities and inflicting US$42.9 billion in damage. This earthquake affected around 18 million people across both countries, making it the second most significant event in terms of the number of people impacted. The most far-reaching event was the 2023 drought in Indonesia, which affected 18.8 million people between June and September.

According to the EM-DAT, many catastrophic events have occurred over the past 20 years (Shen & Hwang, 2019), as shown in Table 1.

**Table 1.** Catastrophic events over the past 20 years

| Date | Location | Disaster | Consequences |
|---|---|---|---|
| December 26, 2004 | Sumatra | Earthquake (magnitude of 9.15) | Triggered a devastating tsunami that impacted Indonesia, Thailand, India, Sri Lanka, and neighboring countries. The disaster claimed between 230,000 and 280,000 lives, left 43,000 missing, and destroyed villages and tourist destinations. |
| January 13, 2010 | Haiti | Earthquake (magnitude of 7.0) | Approximately 316,000 people perished, and about 80,000 buildings were destroyed in the capital city of Port-au-Prince and surrounding areas. |
| May 2, 2008 | The Irrawaddy Delta and southern Yangon | Cyclone (Nargis) | Wind speeds reached 240 kilometers per hour. Around 140,000 people lost their lives, and 2.4 million were severely impacted. |
| May 12, 2008 | Sichuan Province in China | Earthquake (magnitude of 7.8) | The earthquake resulted in the deaths of approximately 87,600 individuals. |
| October 8, 2005 | Pakistan and Indian-administered Kashmir | Earthquake (magnitude of 7.6) | The earthquake hit parts of Pakistan in the northeast of Islamabad, killing over 73,000 people. It also affected Indian-administered Kashmir, where 1,244 people were killed. |
| December 26, 2003 | Kerman Province in Iran | Earthquake (magnitude of 6.6) | The earthquake leveled the ancient city of Bam, claiming 31,000 lives. |
| March 11, 2011 | Japan | Earthquake (magnitude of 9.0) | The earthquake led to a tsunami, which killed approximately 15,690 people. The disaster triggered the most significant nuclear crisis since the Chernobyl disaster of 1986. |
| January 26, 2001 | Gujarat in India | Earthquake (magnitude of 7.9) | The earthquake caused at least 14,000 deaths, leaving more than 150,000 injured. |
| April 25, 2015 | Nepal | Earthquake (magnitude of 7.8) | The earthquake led to the deaths of nearly 9,000 people. |
| September 28, 2018 | Sulawesi, Indonesia | Earthquake (magnitude of 7.5) | The earthquake triggered a 1.5-meter tsunami and caused more than 4,300 deaths. |
| August 14, 2021 | Haiti | Earthquake (magnitude of 7.2) | The earthquake resulted in the deaths of more than 2,200 people and damage to or destruction of about 13,000 homes. |
| August 29, 2005 | The United States | Hurricane (Katrina) | The hurricane made landfall in New Orleans, breaching flood defenses and submerging much of the city under 4.57 meters of water. Approximately 1,800 people died, with most fatalities occurring in Louisiana, though Mississippi was also severely affected. |
| 2023 | Turkey and Syria | Earthquake | Two powerful earthquakes struck southern Turkey and northwestern Syria just hours apart, with the death toll surpassing 51,000 and devastating entire towns across both countries. |

## 3. Response of Industry 4.0 in Crisis Situations

Several leading countries have in recent years created local programs for the development and adoption of Industry 4.0 technologies. In Germany where this concept was born, it was called the “High-Tech Strategy 2020.”

The United States established the "Advanced Manufacturing Partnership"; China initiated the "Made in China 2025" program; and France launched "La Nouvelle France Industrielle."

It has been found that the development cornerstones for Industry 4.0 are good internet connections, local broadband connections, high-capacity international connections, redundant connections, as well as national server farms and cloud computing service providers (Marcucci et al., 2021). There has also been a concern about the disruption or complete interruption of internet connections and normal electricity supply during the COVID-19 pandemic, especially with the energy crisis caused by the war in Ukraine.

Industrial Ethernet is the term used for the use of Ethernet protocols in industrial environments, which is related to the automation processes of industrial plants. Networking industrial plants is a very important topic and a necessity that is inevitably imposed in modern automation, where any disruption of internet connections would be disastrous (Farsi & Zio, 2019).

Synergies between different technologies that can help managers build multi-technology support systems have also been identified. Especially after the COVID-19 pandemic, the importance of employees' digitalization capabilities, problem-solving skills, and creative thinking to fully utilize the potential of Industry 4.0 has been confirmed, which enables managers to cope with crisis challenges, providing a strong argument for investing in Industry 4.0 training measures (Xu et al., 2021).

Industry 4.0 is transforming traditional industry operations and business models by bringing significant changes to operational activities. It supports maintenance, enhances predictive capabilities, and optimizes resources, which are crucial for effectively overcoming challenges in crisis situations. Industry 4.0 represents the digital transformation of industries, integrating advanced technologies into key sectors. The aim is to convert traditional factories into smart ones, supporting the development of a circular economy with substantial economic, environmental, and social benefits.

New technologies, such as block chain, the Internet of Things (IoT), and cloud computing, can optimize energy production, transmission, and trade from renewable sources. New approaches were discussed to increase energy efficiency and resolve grid congestion. Strategies of Industry 4.0 were proposed to minimize the wastage of excess energy and examine methods to handle and anticipate fluctuations in energy markets.

Predictive Maintenance 4.0, a new type of maintenance for these systems, relies on AI for continuous system monitoring during production to detect the causes and anomalies in equipment operation. This new maintenance system provides the ability to predict what was previously unpredictable. The new Industrial Revolution, known as Industry 5.0, is moving towards a return of human labor and intelligence to the industrial framework, or the synergy of humans and machines to improve production and maintenance efficiency. Moving towards Industry 5.0 involves reducing dependence on state critical infrastructures and creating similarly independent supply and sales chains. The future of Industry 4.0 is to have a self-sustaining equipment system. Self-sustaining systems can create more reliable, reconfigurable, and adaptable systems, especially in systems with a critical component failure rate, by integrating adaptive systems with modular design. Indeed, integrating independence from critical infrastructures into the self-sustaining system is one possible model of response to the high risk of modern business associated with critical infrastructure collapse and the energy crisis (Jovančić et al., 2022).

## 4. Evolutionary Direction of Industry 4.0 After Crisis Events

The Industry 4.0 evolution includes the following strategies in the near future: a) Improvement in energy production management; b) Widespread application of heat pumps; c) Unconventional energy sources; d) Small-scale distributed generation; e) Digitalization of energy distribution management systems; f) Free control over the production of electricity; g) Demand-side management; h) The application of higher efficiency energy-saving equipment; i) The application of thermal storage systems; j) The use of storage systems; and k) Reduction in the consumption of reactive power.

There is an obvious shift towards RES in modern industry for not only environmental protection but also for partial or complete energy independence of a company. Industry 4.0, as the bearer of modern production technologies, has managed to make a significant leap in new technologies and their application in a relatively short time. Even though market indicators show a strong increase in the sale of solar equipment, there has also been an increase in the sale of technologies for electricity production from hydrogen through fuel cells, equipment for electricity production from biomass, as well as equipment for using geothermal energy (Farsi & Zio, 2019; Lotfi et al., 2021).

There is still a long road ahead for manufacturers of electricity production equipment from RES to the point where they will be able to replace the consumption of fossil fuels in electricity production. However, this is not about achieving a high level of awareness of the need to preserve the ecosystem of planet Earth but about the risk brought by the crisis in the energy market (Figure 1).

A locally established energy-independent community has its basis in the introduction of distributed energy resources, i.e., distributed electricity generators with a combination of electricity storage in a two-way combination that provide a hybrid energy resource, i.e., the concept of smart grids (Strezoski, 2017).

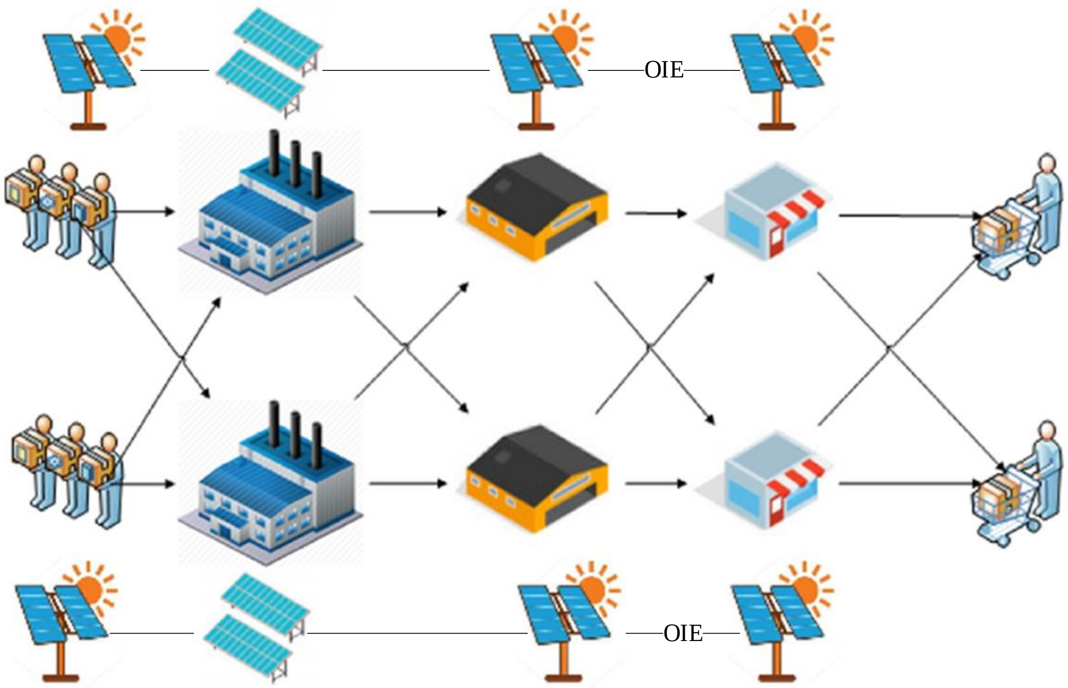


**Figure 1.** Basis of an energy-independent commune based on energy-independent companies with the help of RES (Lotfi et al., 2021)

Namely, due to the problem of balancing the electricity produced in large power plants and fluctuations in consumption on a daily basis, passive distribution networks become active and take over the role of the distribution system. What is most important for the concept of energy-independent communities is the trend for parts of low-voltage distribution networks, such as microgrids, to become autonomous and be able to function independently of the rest of the power system. The functionality of energy-independent communities lies in the large number of distributed electricity generators that are harmonized with the rest of the power system. Therefore, this concept can take the form of a virtual power plant in the future (Strezoski, 2017).

In the case of the Republic of Serbia, which is the only one capable of developing virtual nationwide power plants in a short period, the concept of relying on virtual power plants in industrial energy is extremely important to eliminate the existing collapse risk of the Power System of Serbia (PSS) in the shortest possible time. However, after the establishment of energy-independent community systems in the next period, it can be upgraded with RES electricity producers because the strategic advantage of virtual power plants is their proximity to electricity consumers, where electricity losses are minimized and surpluses of generated electricity can be stored in distribution warehouses.

The main problem is that Serbia does not have adequate legal basis or social awareness and support to support the development of local energy communities. Currently, local movements have emerged, with the aim of preventing certain RES projects that are considered to have a negative impact on the environment and microclimate in the locations designated for construction (small hydropower plants).

It should be noted that in Serbia, there is a tradition of organizing citizens to collectively solve energy supply problems. This fact should be used, and based on well-known models, such as cooperative connections, to create a framework for launching local energy initiatives (Parović, 2022).

### 4.1 Case Study of Vrbas Energy Virtual Commune

The town of Vrbas has a strong industry with thermal blocks, while the company Mirotin Ltd. from Vrbas has built a power plant on biogas obtained from cow manure from its cattle farm (Lavrnić, 2019). In Vrbas, several large companies have the capacity to advance industrial energy solutions, including Carnex, Vital and Bačka, which are a meat processing company, an oil production plant, and a sugar factory, respectively. In 2012, the company Mirotin constructed a biogas power plant with a capacity of 1 MW, which generates energy from manure sourced from its dairy farm, utilizing the electricity to power its irrigation system during the growing season.

Furthermore, Carnex operates a thermal power block continuously throughout the year, which can be readily upgraded to a combined heat and power (CHP) plant to supply the majority of the required electricity for the local community. The active agricultural production within this municipality provides the potential for biomass combustion in all three major factories, enabling the supply of electricity to neighboring municipalities.

The system of switches and radial connections of major consumers in the Serbian Electrical Energy System (EES) allows, with minor adjustments and manual disconnection from the remaining high-voltage transmission network, the creation of separate energy-independent communes. To reduce the risk of a complete collapse of the EES, it is not crucial whether these energy communes operate independently from the EES or remain in a preparatory mode ready to be activated in the event of a system collapse (Figure 2).

In the first phase of implementing this concept, the objectives are as follows:

a) To upgrade the existing thermal units in the CHP plants within major companies;

b) To install gas generators in companies that do not have continuously active thermal units (24/7);

c) To develop an energy-independent commune in collaboration with local government and the Electric Power Industry of Serbia (EPS), separating it from part of the high- and low-voltage distribution networks, and integrate all critical infrastructure within the local government area;

d) To repurpose the municipal heating plant into a CHP plant.

Serbia possesses 2.6 million tons of biomass, although only a minimal portion of this energy resource is currently employed in electricity generation. The industrial energy sector is uniquely positioned to rapidly enhance existing thermal power blocks and backup power supplies, initially by transitioning to natural gas as the primary energy source. Achieving energy independence for these companies could substantially mitigate the risk of a collapse within the PSS, thereby ensuring the continued operation of critical infrastructure within the local community and maintaining a stable electricity supply for the population during such an event.

Through the implementation of a system of switches and radial connections among major consumers within Serbia's EPS, a separate energy-independent community could be formed.

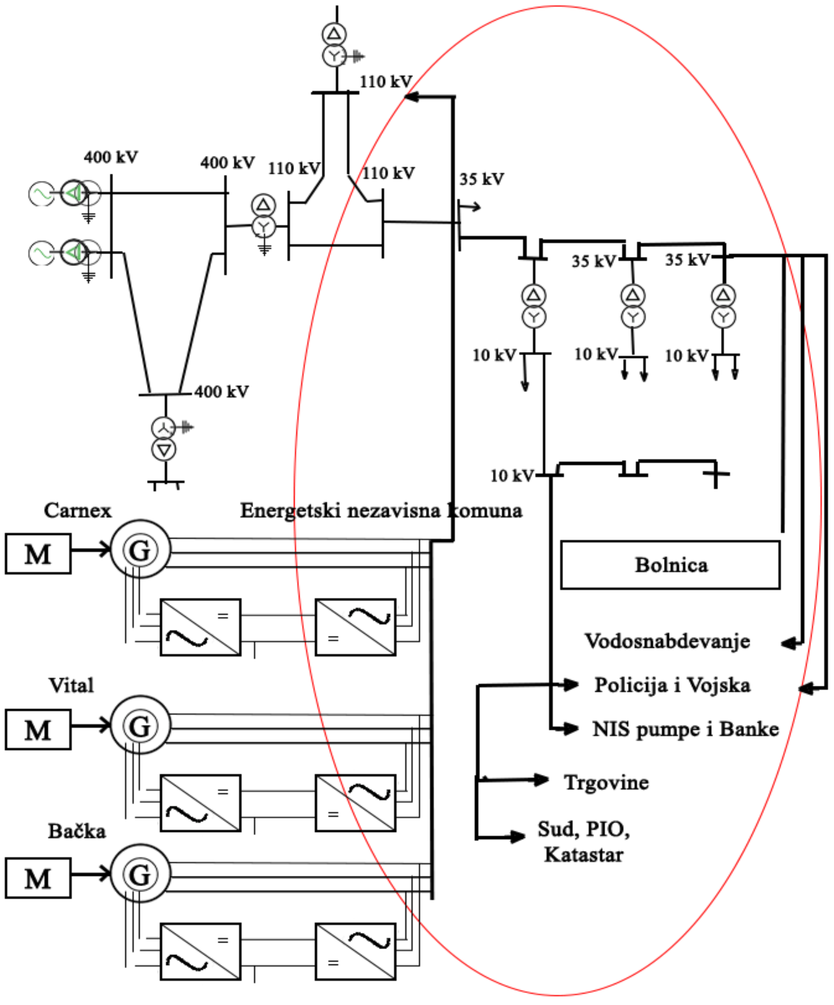


**Figure 2.** Power system based on energy-independent communities in Vrbas (Lavrnić, 2019)

## 5. Response of BCM to Natural Disasters and Energy Crises

Significant disruptions to the work environment have increasingly posed risks to business continuity across various sectors. Traditionally, the field of business continuity has focused predominantly on the IT segment and data preservation. However, recent developments have broadened this focus to encompass the continuity of production processes, maintaining market relationships, and securing energy sources.

The COVID-19 crisis, as well as the recent conflict between the Russian Federation and Ukraine, has created an atmosphere of uncertainty in economic sectors, which consequently leads to the need to reconsider the foundations of modern business and engage in reengineering. The uncertainty during the pandemic has significantly slowed down many industrial sectors, and some, such as tourism and hospitality, have been almost extinguished for a certain period (Clark, 2020).

There has been a particular need for reengineering the entire business concept in the healthcare and education sectors. The neglect of preparations for such scenarios at the company level has consequently led to a lengthy recovery process and, for some, the loss of market leadership positions (Hiles, 2014).

Alongside continuous monitoring strategies, the need of customers in an era of mass closures has led to significant innovations and changes in business. However, the consequences of the war in Ukraine have brought new fears and uncertainties regarding the energy security of the country as well as the companies themselves (Lindstedt et al., 2017). Consequently, new moments have appeared with the trend of a new business continuity approach (i.e., BCM), where the focus shifts from preserving IT hardware to preserving production processes and business communication with the surrounding market (i.e., with operational companies in crisis conditions) (Majstorović et al., 2022; Sheffi, 2015).

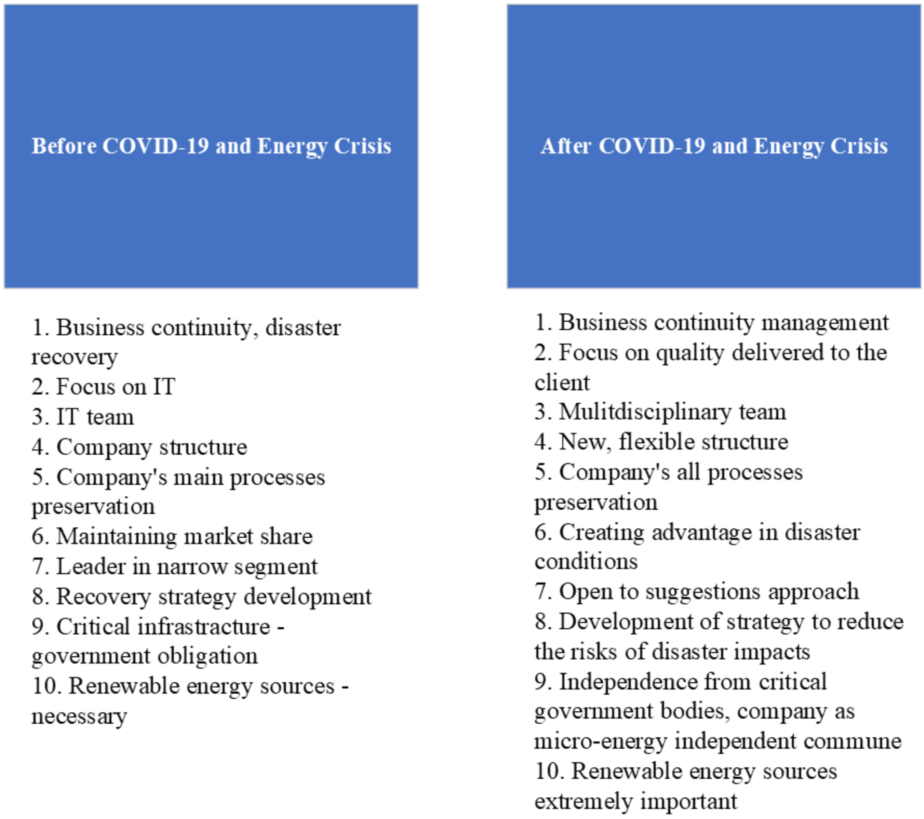


**Figure 1.** Diagram of BCM before and after the COVID-19 and energy crisis

Companies have been forced to introduce the following changes in response to the aforementioned challenges:

a) Shifting work from offices to employees' homes through various applications.

b) Increased digitization of business.

c) Conducting meetings with clients online instead of in offices.

d) Development of contactless sales.

e) Understanding that business continuity entails not only preserving the hardware and data of the company but the entire business.

f) The need for companies' energy independence by converting thermal blocks into electricity producers and introducing other sources such as solar, wind, and water.

g) Development of loyalty programs for their clients.

h) Communication with clients has proven more important than other sectors during the crisis.

i) Healthcare has turned to online diagnostics, virtual medical offices, and telemedicine.

j) Banking has strongly shifted to e-banking without branches and direct customer contact.

k) Education has completely transformed into e-education during the pandemic, and a significant part remains online.

In summary, many changes have occurred that were unthinkable before the COVID-19 pandemic and the energy crisis (Asutosh et al., 2020; Botzen et al., 2019; Emenike & Falcone, 2020; Espinoza & Yanira, 2021). These changes are clearly visible in Figure 3 above.

## 6. Conclusion

The global crises, particularly the COVID-19 pandemic and the 2021 energy crisis, have revealed significant vulnerabilities in modern industrial and economic systems, making it imperative to rethink traditional approaches to both production and energy management. Industry 4.0 has emerged as a critical driver in addressing these challenges, facilitating a shift toward resilient, flexible, and technology-driven business models. The digital transformation brought forth by Industry 4.0 not only enhances operational efficiency through innovations like Predictive Maintenance 4.0 and AI-based monitoring but also optimizes the deployment of RES and smart grid technologies. These developments are key to safeguarding businesses against future crises, whether they stem from supply chain disruptions, energy shortages, or geopolitical instability.

The case study of Vrbas energy virtual commune exemplifies how local initiatives can lead the way in fostering energy independence, a concept that is increasingly essential as global energy systems face pressures from climate change, political instability, and resource scarcity. Through strategic implementation of distributed energy resources and integration of biomass, biogas, and other renewables, such initiatives showcase the potential for building energy-independent communities that not only mitigate risks but also contribute to economic and environmental sustainability.

Moreover, the study highlights the need for a paradigm shift in BCM. The traditional focus on IT infrastructure and data preservation must now broaden to include energy resilience and operational continuity in crisis conditions. By embedding energy autonomy and distributed energy systems into business strategies, companies can reduce reliance on state critical infrastructures and create more adaptive supply chains. This represents a fundamental change in BCM, pushing beyond mere contingency plans toward the establishment of self-sustaining systems.

In summary, Industry 4.0 and BCM must work hand in hand to ensure that industries are not only prepared to survive crises but also equipped to thrive in a post-crisis world. The integration of ADT, renewable energy systems, and localized energy solutions offers a pathway toward a more resilient and sustainable future. The study contributes to this evolving discourse by outlining the practical applications of energy-independent communes, the role of predictive technologies in crisis management, and the reengineering of BCM frameworks to meet the demands of a world increasingly shaped by uncertainty.

## Data Availability

The data used to support the research findings are available from the corresponding author upon request.

## Conflicts of Interest

The authors declare no conflict of interest.

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