Adoption of smart energy technologies in the context of sustainable development

Elena Korneeva\textsuperscript{1,2}*, Aizhan Omarova\textsuperscript{3}, and Oksana Nurova\textsuperscript{2}

\textsuperscript{1} Financial University under the Government of the Russian Federation, 49, Leningradsky Prospekt, Moscow, 125993, Russia
\textsuperscript{2} Togliatti State University, 14, Belorusskaya St., Togliatti, 445667, Russia
\textsuperscript{3} Yessenov University, Microdistrict 32, Aktau, 130000, Kazakhstan

Abstract
This paper focuses on the analysis of the shift towards smart energy technologies in a post-COVID era marking and describing it as a process of transition from crisis to an immense opportunity. The COVID-19 pandemic with its lockdowns and social distancing made people to spend more time indoors helping them to realize the extent of the climate change and global warming and their effect on the human lives. In addition, it also caused a noticeable shift in consumer behaviour towards energy consumption and re-thinking energy efficiency. Central to this transformation is the increasing adoption of smart energy technologies, which are playing a pivotal role in enhancing energy efficiency within households and across communities. Our paper demonstrates how smart energy technologies not only lead to significant savings on utility bills but also reduce the environmental impacts by lowering carbon emissions and increase the acceptance of the novel energy technologies. Additionally, they make consumers worldwide aware of the ways and solutions how to reduce their energy consumption altrends and minimize the negative impacts of human economic and social activities on the environment via adapting green energy technologies and shifting in the direction of the renewable energy solutions.

1 Introduction

The COVID-19 pandemic has been a defining moment for multiple sectors across the globe, catalyzing unprecedented disruptions and compelling industries to reevaluate their operational paradigms. Among these, the energy sector faced its own unique set of challenges and opportunities as the pandemic unfolded\textsuperscript{1,2}. The impact of COVID-19 on the energy sector was multifaceted, touching upon aspects of production, consumption, investment patterns, as well as regulatory frameworks. As countries went into lockdown to curb the spread of the virus, there was a significant shift in energy demand patterns, underscoring the need for resilience and adaptability in energy systems\textsuperscript{3}. This situation exposes the vulnerabilities in traditional energy networks and highlighted an urgent need for innovation towards more sustainable and resilient smart energy technologies\textsuperscript{4}.\textsuperscript{*}

* Corresponding author: korneeva1207@yandex.ru

© The Authors, published by EDP Sciences. This is an open access article distributed under the terms of the Creative Commons Attribution License 4.0 (https://creativecommons.org/licenses/by/4.0/).
During this period of global standstill, industrial activities saw a remarkable downturn as the transportation sectors nearly halted due to travel restrictions, and commercial spaces remained largely unoccupied. Consequently, there was an initial sharp decline in overall energy demand. However, this decrease was not uniform across all sectors or regions. Residential energy consumption spiked as people spent more time at home due to lockdown measures and work-from-home arrangements became widespread. This uneven pattern of consumption exposed how inflexible existing energy infrastructures were when faced with sudden changes in demand. Moreover, the pandemic underscored the critical importance of reliable energy access during crises. Healthcare facilities required uninterrupted power to treat patients and store vaccines at precise temperatures. Meanwhile, digital platforms became essential for maintaining economic activities remotely. These conditions emphasized that beyond mere supply considerations, quality and reliability of power are paramount for societal resilience. The financial strain on utility providers also became apparent as they grappled with fluctuating demand alongside pressures to suspend disconnections for non-payment amid economic hardships faced by consumers. The resulting financial implications were profound not only for utilities but also for ongoing investments in renewable energy projects which experienced delays or cancellations. In response to these challenges arises a silver lining: an accelerated shift towards smart energy technologies characterized by digitalization, decentralization, and decarbonization which are the principles that promise enhanced flexibility within global energy systems. The crisis brought about by COVID-19 has acted as a catalyst for change towards more sustainable practices within the sector.

Our paper shows that even though the pandemic disrupted traditional operations within the energy sector significantly, from production chains to consumer behaviour, it simultaneously paved pathways toward innovation. By highlighting existing vulnerabilities within current systems while demonstrating that change is possible under pressing circumstances turning crisis into opportunity by advancing smart technology solutions aimed at creating more resilient future-ready globalized energy systems.

2 COVID-19 pandemic and smart energy technologies

...
Smart energy technology, encompassing a wide array of devices such as smart thermostats, lighting systems, and appliances, offers an innovative solution to managing energy consumption more effectively. These devices can learn from people's habits and adjust themselves accordingly to ensure optimal energy use without sacrificing comfort. And the popularity of these smart devices is growing in the past years.

Figure 1 that follows shows the dynamic of smart meters deployment by depicting the shipments in millions of units in North America, Europe, Asia Pacific region, as well as the rest of the world between 2018 and 2024 based on the Berg Inside 2024 report [13]. (Figure 1)

Moreover, the integration of the smart energy technologies with renewable energy sources has become increasingly seamless. Solar panels paired with smart energy systems can now more efficiently manage power storage and distribution throughout a home. This synergy allows for an even greater reduction in reliance on non-renewable energy sources, pushing consumers closer to achieving net-zero homes—residences that produce as much renewable energy as they consume [14]. The pandemic has underscored the importance of adaptability and resilience in facing unforeseen challenges. In this light, smart technology offers enhanced control over one’s environment allowing individuals not only to monitor their energy usage through intuitive apps but also to make immediate adjustments remotely. This level of control extends beyond mere convenience. It represents a paradigm shift in how individuals perceive their role in global sustainability efforts [15]. Furthermore, governments and utility companies have recognized this shift towards sustainable living by offering incentives for adopting smart technologies. Rebates, tax credits, and subsidized pricing models, lower financial barriers for consumers eager to participate in this green transition but cautious about initial investments [16]. As the world navigates through and beyond the COVID-19 pandemic era, it becomes very clear that our relationship with our living spaces is evolving towards a greener future. Smart technology stands at the forefront of this change, not just as tools for convenience but as essential components for achieving greater energy efficiency and sustainability goals. The collective embrace of these technologies reflects growing consumer awareness about environmental issues alongside a commitment to action [17]. Additionally, governments worldwide have seized this moment to align economic recovery efforts with climate goals by prioritizing green investments. Incentive programs aimed at accelerating the deployment of renewable energies and supporting infrastructure.
electric vehicles (EVs) are examples where policy has been geared towards fostering a sustainable recovery [18]. Such initiatives further stimulate market growth for smart technologies by integrating renewable sources into existing power grids more effectively or managing EV charging loads without straining available resources [19, 20].

Last but not least, the recent advancements in Internet of Things (IoT) (as well its sub-section called the Internet of Energy (IoE)) during the duration of the pandemic have played a pivotal role in enabling these shifts towards smarter energy applications. IoT’s capability to connect various devices within an integrated network allows for unprecedented levels of automation and efficiency in monitoring and controlling power systems remotely [21].

In essence, while COVID-19 presented numerous challenges across sectors globally, energy included, it also served as an impetus for reimagining future power systems through the lens of innovation and sustainability. The accelerated transition towards smart energy technologies is emblematic of society’s resilience, transforming crisis-driven constraints into opportunities that pave way for more adaptive, and eco-friendly solutions.

3 Accelerating post-pandemic energy transition

The COVID-19 pandemic has undeniably reshaped many aspects of daily life, not least among them consumer attitudes towards energy efficiency and sustainable living practices. As the world grappled with unprecedented challenges, a significant shift in perspective emerged, highlighting the interconnectedness of health, environment, and economy [22]. This evolving consciousness around sustainability reflects a broader reconsideration of personal and collective priorities in the face of global crises. During the pandemic, lockdowns and restrictions forced a large portion of the population to spend more time at home, leading to an increased awareness of household energy consumption [23]. The surge in remote work and education underscored the importance of efficient energy use not just for environmental reasons but also for managing household expenses amidst economic uncertainty. This heightened visibility of energy consumption in daily life propelled consumers to seek ways to minimize their carbon footprint through more sustainable living practices [24].

Moreover, the stark reminder of human vulnerability to global threats has intensified interest in resilience and self-sufficiency—concepts central to sustainable living. Individuals are now more inclined to consider how their choices impact not only their immediate surroundings but also the broader ecosystem. This includes a growing preference for renewable energy sources over fossil fuels, driven by a desire to contribute to a more sustainable and resilient future [25]. The pandemic also spotlighted the fragility of global supply chains, prompting consumers to rethink their consumption patterns and prioritize locally sourced and produced goods. This shift not only supports local economies but also reduces carbon emissions associated with long-distance transportation [26]. The emphasis on localism is part of a larger trend towards minimizing waste and adopting circular economy principles—both key aspects of sustainable living. Importantly, these changing attitudes are not limited to individual actions; they’re influencing demands on businesses as well. Consumers increasingly expect transparency regarding corporate sustainability practices and prefer brands that demonstrate commitment to environmental stewardship. This expectation is driving companies across industries, from technology to fashion, to innovate greener products and operations. In essence, the COVID-19 pandemic has served as a catalyst for reevaluating what it means to live sustainably in the 21st century [27]. The collective experience has fostered greater empathy towards our planet and its finite resources, encouraging more mindful consumption habits that prioritize long-term well-being over short-term convenience or cost savings. As society continues navigating post-pandemic recovery, these changing attitudes towards sustainable living practices offer hopeful.
prospects for building a more resilient world that harmonizes human activities with nature’s limits.

Figure 2 shows the results of the worldwide search using Google Trends interactive tool for the keywords "smart energy", "renewable energy", and "COVID-19 pandemic" between 2020 (when COVID-19 was declared a pandemic by the World’s Health Organization) and 2024. The results have been obtained using the Google Trends toolkit that is based on the “Interest over Time” (IoT) — the search interest for a specific keyword on Google search engine relative to the highest search point for the given region and time period.

From Figure 2, it becomes quite clear that while the IoT for the renewable energy has traditionally been high during the period in question, the interest in COVID-19 pandemic coincides with that of the smart energy that has gained its popularity in the times of the pandemic (2020-2022).

Fig. 2. Google Trends results for the keywords “smart energy”, “renewable energy” and “COVID-19 pandemic” (2020-2024)
recognizing that accelerating the transition to smart energy is not only crucial for climate action but also for economic recovery. With regard to the above, the investments in green infrastructure have become central pillars of post-COVID recovery plans, aiming both to create jobs and stimulate sustainable growth. Initiatives such as increasing renewable energy capacity, modernizing grid infrastructure, and incentivizing EVs adoption are gaining momentum.

However, this acceleration also calls for overcoming significant hurdles ranging from technological innovation gaps to regulatory frameworks that must evolve at pace with market changes. Public-private partnerships are emerging as key enablers in this journey by pooling resources for research & development (R&D) while fostering an environment conducive to rapid deployment of smart technologies.

As the world adapts to a post-COVID era by accelerating the transition towards smarter energy systems, people should not merely respond reactively, they should proactively shape an equitable, resilient future with clean technology-driven economies that thrive on sustainability rather than survive on contingency.

4 Pandemic and renewable energy

The global pandemic gave human society a unique opportunity to rethink and reshape its energy paradigms. The crisis has uncovered the vulnerabilities of traditional energy systems, propelling a significant shift towards smart energy technologies. Among these innovations, harnessing renewable energy sources stands out as a cornerstone for building sustainable solutions in a post-COVID world. The transition towards renewable energy is not merely an environmental imperative but also an economic and social one. The volatility of fossil fuel markets witnessed during the pandemic underscored the need for more resilient and reliable sources of energy. Renewable resources, such as solar, wind, hydroelectric, and geothermal power, offer a pathway to security and stability. They are abundant, available globally, and emit little to no greenhouse gases or pollutants. Smart technologies play a pivotal role in integrating these renewable sources into our energy systems effectively. Advances in digital technology have enabled smarter grid management that can handle the variability and decentralized nature of renewable power generation. Smart grids can dynamically balance supply and demand, incorporate storage solutions to manage intermittency issues associated with renewables like solar and wind power, and enhance efficiency through real-time data analytics.

Moreover, these technological advancements encourage greater consumer engagement in their own energy consumption patterns. Smart meters and home management systems allow individuals to monitor their usage more closely, make informed decisions about when to use electricity most efficiently and even feed excess power generated from rooftop solar panels back into the grid. This not only reduces carbon footprints but also lowers utility bills—a win-win scenario in the pursuit of sustainability.

The move towards harnessing renewable sources through smart technologies embodies a holistic approach to addressing climate change while fostering economic resilience in a post-pandemic era. It underscores how crisis can indeed catalyse opportunities for innovation that pave the way for more sustainable futures. As the new paradigms of resilience and sustainability are being set in place, embracing renewable energies augmented by smart technologies would be paramount in navigating towards greener and more sustainable future.

5 Post-pandemic smart grids and storage energy systems


opportunity to transform the energy systems. The shift towards smart energy technologies, particularly through the implementation of smart grids and energy storage systems, stands as an example of resilience and innovation in a post-COVID era. Smart grids represent a revolutionary leap forward from traditional electrical grids. By integrating digital technology that allows for two-way communication between utility companies and consumers, smart grids provide real-time data about power consumption, enhancing efficiency and reliability. In the context of post-pandemic recovery, these grids offer an agile response mechanism to fluctuating demands, which is a critical capability when considering the increased unpredictability in consumption patterns due to changing work habits such as remote working. Moreover, smart grids facilitate the integration of renewable energy sources into the grid. This is essential in building resilience against future crises by reducing dependency on fossil fuels and mitigating climate change risks. The ability to seamlessly connect with decentralized renewable sources enables a more robust energy supply chain that can withstand external shocks more effectively. Complementing smart grids are advanced energy storage systems (ESS). The deployment of ESS is pivotal in addressing one of renewable energy's most significant challenges represented by its intermittency. By storing excess energy generated during peak production times—be it from solar during sunny days or wind during windy conditions—ESS ensures that electricity is available when demand exceeds supply or when generation is low. This not only stabilizes the grid but also maximizes the utilization of renewable resources. Furthermore, ESS contributes to enhancing grid resilience by providing backup power during outages and reducing congestion on transmission lines. In the post-COVID era marked by an increasing frequency of extreme weather events due to global warming and climate change, such resilience becomes invaluable. The transition towards smarter energy infrastructures through advanced grids and storage solutions embodies a dual strategy: it leverages technological innovation to not only recover from current crises but also fortify against future uncertainties. As the world navigates through these challenging times, embracing these technologies offers a pathway towards sustainable development and long-term societal resilience.

6 Conclusions

As the world is quickly moving away from the shadows of the COVID-19 pandemic, a unique opportunity presents itself. The crisis has undeniably showcased the vulnerabilities in our global systems, including those of energy production and consumption. However, it has also illuminated a path toward innovation and resilience through smart energy technologies. Seizing this moment to pivot towards a more sustainable and resilient future is not merely an option but a necessity for societies worldwide. The transition towards smart energy technologies in the post-COVID era is emblematic of our collective ability to learn, adapt, and evolve in the face of adversity. This movement is not just about replacing old systems with new—it is also about reimagining what the future of this planet might look like. Smart grids, renewable energy sources such as solar and wind, energy storage solutions, and digital tools for managing demand are all pieces of a complex puzzle that promises not only to mitigate the impacts of climate change but also to usher in an era of unprecedented efficiency and reliability in how we produce and consume energy. The adoption of these technologies offers multiple benefits that extend beyond environmental sustainability. Economically, it paves the way for job creation in new sectors, such as engineering, manufacturing, installation, or maintenance, and supports economic recovery by channelling investments into innovative industries. Socially, it has the potential to democratize energy access through decentralized systems that empower communities and reduce dependencies on fossil fuels or large-scale infrastructure inclined to disruption.
Moreover, smart energy technologies are inherently designed to be adaptive. They can respond dynamically to changes in supply and demand while integrating seamlessly with other technological advances such as electric vehicles or smart homes. This adaptability is crucial as people face not only ongoing challenges from climate change but also unforeseen crises that may arise in the future. However, realizing this vision requires concerted effort across all levels of society: from policymakers who create supportive regulatory frameworks and incentives to businesses that prioritize sustainability in their operations, from researchers who continue pushing the boundaries of what is technologically possible to individuals who embrace changes in their consumption habits.

To summarize this all-among all the uncertainties post-COVID-19 lies an unmissable opportunity: leveraging smart energy technologies for a sustainable resurgence. This shift is more than just an environmental imperative, it represents a strategic move towards building economies that are robust yet flexible enough to withstand future shocks while ensuring equitable access to resources for all members of society. As humankind stands at this crossroads between crisis and opportunity, it needs to choose a path that leads toward resilience which is the one marked by innovation-driven growth fostered by sustainable economic and social practices.

References

2. V. van Zoest, K. Lindberg, F. El Gohary, C. Bartusch, Energy and AI, 14, 100298 (2023)
4. Q. Wang, R. Huang, R. Li, Energy Strategy Reviews, 41, 100845 (2022)
5. G. Rausser, W. Strielkowski, G. Mentel, Energies, 16(3), 1478 (2023)
7. A. Abu-Akel, A. Spitz, R. West, PloS one, 16(2), e0245100 (2021)
13. Berg Insight. Smart metering in Europe. Available at: https://www.berginsight.com/smart-metering-in-europe (accessed on 27.03.2024)
14. B. Ramasubramanian, S. Ramakrishna, Sustainable Earth Reviews, 6(1), 17 (2023)
15. V. Kaftan, W. Kandalov, I. Molodtsov, A. Sherstobitova, W. Strielkowski, Sustainability, 15(4), 2876 (2023)
18. G. Trencher, Energy Reports, 6, 2503-2519 (2020)
22. B. Gajdzik, R. Wolniak, R. Nagaj, B. Žuromskaitė-Nagaj, W. Grebski, Energies, 17(4), 947 (2024)
23. S. Axon, T. Lent, A. Njoku, Energy Research & Social Science, 102, 103188 (2023)
27. R. Fenner, T. Cernev, Futures, 128, 102726 (2021)
29. Google Trends. Available at: https://trends.google.com (accessed on 28.03.2024)
32. E. Zaidan, A. Ghofrani, A. Abulibdeh, M. Jafari, Frontiers in Energy Research, 10, 852092 (2022)
34. J. Feng, N. Wang, G. Sun, Sustainability, 14(9), 5096 (2022)
35. R. Bhattacharya, D. Bose, Environmental Progress & Sustainable Energy, 42(1), e14018 (2023)
36. M. Khalid, Energy Strategy Reviews, 51, 101299 (2024)
42. O. Agboola, M. Tunay, Journal of Cleaner Production, 428, 139304 (2023)