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Review Article

Energy Management in Disasters: The Effective Role of Renewable Energy Sources

[1]Dilek ŞAHİN CÜCE[*], [2]Hüseyin CÜCE

[1*]Giresun University, Institute of Natural and Applied Sciences, Giresun, Türkiye (*ORCID Number:* https://orcid.org/0000-0003-1260-0284)

[2]Giresun University, Faculty of Engineering, Department of Environmental Engineering, Giresun, Türkiye (*ORCID Number:* https://orcid.org/0000-0002-3590-681X)

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Abstract

Since the last decade, natural disasters caused by regular geological activities and global warming have continued to demonstrate the need to optimize existing energy resources and increase the renewable energy potential in national development by disrupting the security of supply of humanity. Inter-institutional cooperation, rational and sustainable energy policies are necessary to increase energy efficiency in disasters in the face of a changing climate. The current situation in energy use before, during and after the disaster should be monitored using improvement techniques. It is important to prepare action plans for the integration and installation of alternative and renewable energy sources required to meet the energy needs arising from disasters.

Keywords
Renewable Energy
Disaster
Climate Change
Efficiency

Afetlerde Enerji Yönetimi: Yenilenebilir Enerji Kaynaklarının Etkin Rolü

Özet

Son on yıldan bu yana, düzenli jeolojik faaliyetler ve küresel ısınmanın neden olduğu doğal afetler, ulusal kalkınmada mevcut enerji kaynaklarının optimize edilmesini ve yenilenebilir enerji potansiyelinin arttırılması gerektiğini insanoğlunun arz güvenliğini sekteye uğratarak göstermeye devam etmektedir. Kurumlar arası işbirliği, akılcı ve sürdürülebilir enerji politikaları, değişen iklim karşısında afetlerde enerji verimliliğini artırmak için gereklidir. Afet öncesinde, sırasında ve sonrasında enerji kullanımındaki mevcut durum ve iyileştirme teknikleri kullanılarak takip edilmelidir. Afetlerde ortaya çıkan enerji ihtiyacının karşılanması için gerekli olan alternatif ve yenilenebilir enerji kaynaklarının entegrasyonu ve kurulumu için eylem planlarının hazırlanması önemlidir.

Anahtar Kelimeler
Yenilenebilir Enerji
Afetler
İklim Değişikliği
Verimlilik

Corresponding Author Email: dileksahincuce@gmail.com

1. INTRODUCTION

Climate change poses one of the most pressing challenges of our time, with profound implications for ecosystems, economies, and human well-being. Renewable energy stands out as a key solution in the fight against climate change, offering a pathway to decarbonize energy systems and mitigate greenhouse gas emissions. Intergovernmental Panel on Climate Change (IPCC) works on the creation of countries' emission inventories and produces publications. As emphasized in a report by the IPCC, "The widespread adoption of renewable energy technologies is essential for limiting global warming to well below 2 degrees Celsius" [1-2].

One significant aspect of energy efficiency in disaster management is the utilization of renewable energy sources. Research by Saha and Nath (2019) suggests that integrating renewable energy technologies such as solar panels and wind turbines into disaster-prone areas can enhance energy resilience and reduce dependency on centralized power grids. Renewable energy systems are inherently more resilient to disruptions caused by disasters, providing a reliable source of power when conventional energy infrastructure is compromised. The burning of fossil fuels for energy production is a major contributor to climate change, releasing carbon dioxide (CO2) and other greenhouse gases into the atmosphere. Transitioning to renewable energy sources such as solar, wind, and hydroelectric power can significantly reduce these emissions. According to Sachs et al. (2021), increasing the share of renewable energy in the global energy mix is critical for achieving carbon neutrality and avoiding the worst impacts of climate change [3, 4].

Incorporating energy efficiency into disaster management policies requires a multidisciplinary approach and collaboration between government agencies, non-profit organizations, and the private sector. As emphasized by the United Nations Development Programme (UNDP), promoting energy efficiency in disaster risk reduction requires concerted efforts from various stakeholders to integrate energy considerations into resilience-building

initiatives. This necessitates the development of comprehensive frameworks and guidelines that prioritize energy efficiency in disaster preparedness and response strategies [5].

In this article, which reviews the current literature on energy efficiency, an evaluation has been made on disaster-focused sustainable energy management regarding climate change, natural disasters and their effects on energy needs and solution suggestions. Disasters exacerbated by climate change, in addition to endangering human life, can also seriously and irreversibly affect the supply of energy, which is extremely important in meeting basic needs. Events such as hurricanes, floods and wildfires have a significant impact on infrastructure and superstructure, disrupting the entire communication network. The complex network of impacts that these disasters can cause to decrease energy efficiency and increase the need for alternative resource use has been comprehensively examined in this article. It also underlines the urgent need for sustainable management and renewable energy practices to reduce the impacts that disasters can have on the energy ecosystem.

2. ENERGY EFFICIENCY AND CLIMATE CHANGE

Energy efficiency plays a crucial role in disaster management, offering multiple benefits such as reducing energy consumption, minimizing greenhouse gas emissions, and enhancing resilience against adverse events. Incorporating energy-efficient measures into disaster management strategies can significantly improve response and recovery efforts, ensuring sustainability and cost-effectiveness. As highlighted by the International Energy Agency (IEA); Energy efficiency is the first fuel of a sustainable global energy system, emphasizing its importance in mitigating the impacts of disasters. The demand for energy goods has drastically expanded due to global trends and the pressures of industrialization. Consequently, the socioeconomic strategies of nations included in the framework Global energy consumption is seen to be evolving (Fig. 1) [6].

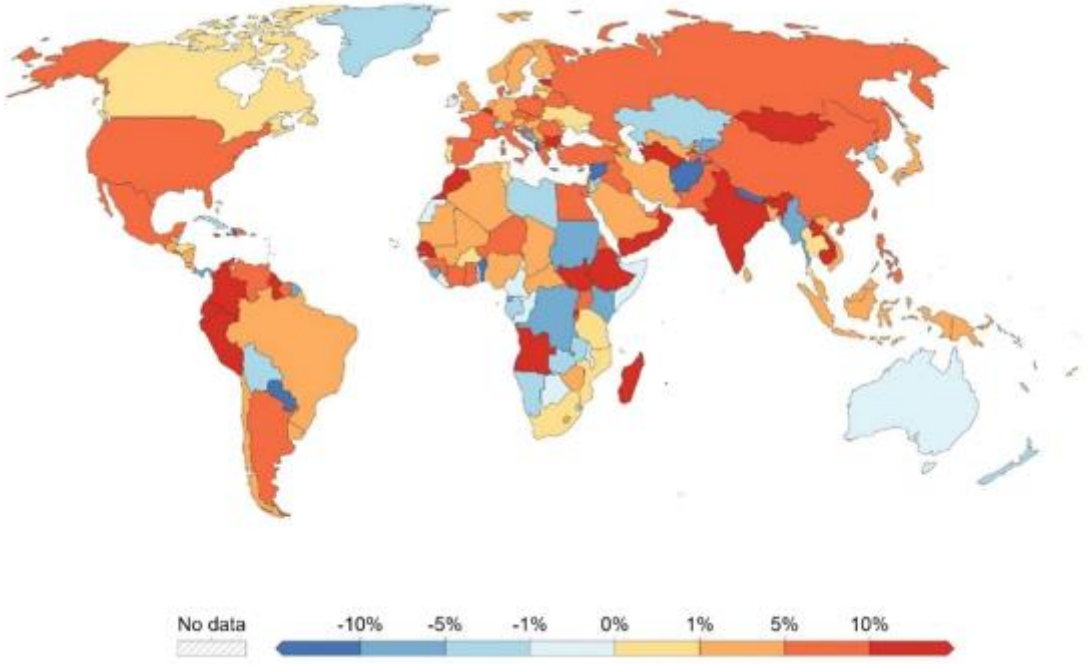

Figure 1. The quantity overall variation in the world's energy usage according to BP Statistics 2022 [7].

Climate change is one of the most pressing challenges of our time, driven primarily by greenhouse gas emissions from fossil fuel combustion. In this context, renewable energy emerges as a critical solution for mitigating climate change by reducing carbon emissions and transitioning towards a low-carbon energy system. As emphasized in a study -The deployment of renewable energy technologies is essential for achieving the emissions reduction targets outlined in the Paris Agreement [8].

The World Bank's guideline states that disasters such heat waves, droughts, floods, earthquakes, and diseases are among the risks. Even if the overall number of natural disasters has decreased over the last 20 years, at least 200 still occur year (Fig. 2).

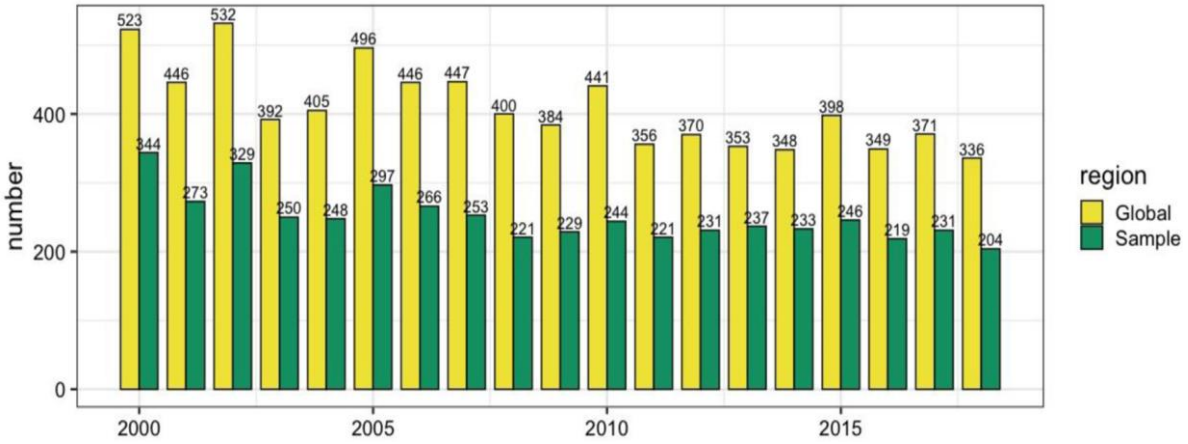

Figure 2. The quantity of disasters that occur globally and in the sample countries according to EM-DAT database [9]

2.1. Disasters and Sustainable Energy

Disasters, whether natural or human-induced, pose significant challenges to communities worldwide. In the face of such calamities, energy efficiency becomes a crucial aspect of disaster management, helping to optimize resources and mitigate the impact on affected populations. As highlighted by research published from Ribeiro et al. (2015), efficient energy management plays a critical role in enhancing the resilience of communities to disasters [10].

Reducing energy consumption or decreasing the consumption of conventional energy is considered as one way to improve energy efficiency. One of the primary advantages of renewable energy sources such as solar and wind power is their ability to generate electricity without emitting greenhouse gases. Solar photovoltaic (PV) systems harness sunlight to produce electricity, while wind turbines convert kinetic energy from wind into electrical power. According to research conducted in 2011 by Jacobson and Delucchi, solar and wind energy are abundant, clean, and inexhaustible resources that can significantly reduce carbon emissions from electricity generation. Furthermore, renewable energy technologies offer scalability and flexibility, making them suitable for diverse applications and geographical locations. Distributed generation systems, such as rooftop solar panels and small wind turbines, empower communities to generate clean energy locally and reduce dependence on centralized fossil fuel-based power plants. As noted in a paper

by Sovacool and Brown (2010), decentralized renewable energy systems enhance energy access and resilience while mitigating climate change impacts [12, 13].

In addition to electricity generation, renewable energy plays a crucial role in decarbonizing other sectors such as transportation and heating. Electric vehicles (EVs) powered by renewable electricity offer a sustainable alternative to internal combustion engine vehicles, reducing emissions and air pollution. Similarly, renewable heating technologies like solar thermal systems and biomass boilers replace fossil fuel-based heating systems, contributing to emissions reductions. In the study conducted McCollum et al. (2018) highlights that electrification of transportation and heating sectors with renewable energy is essential for achieving deep decarbonization and climate resilience [14].

Moreover, renewable energy deployment contributes to economic growth and job creation, fostering a transition towards a green economy. The renewable energy sector has experienced rapid expansion in recent years, attracting investments and creating employment opportunities across various segments of the value chain, from manufacturing to installation and maintenance. A report released by ILO (2019) underscores that renewable energy investments generate more jobs per unit of energy produced compared to fossil fuel-based investments, supporting sustainable development objectives [15].

2.2. Renewable energy practices in disaster management

Natural extreme events are an essential factor that must be taken into account in terms of the security of lives and property or the development of economics and society. In disaster management, the integration of various resources and the processing of data, including monitoring environmental consequences, especially basic problems such as energy needs after disasters, is an effective process. The connotations of energy security have expanded from the concern for regional energy supply and demand balance to considerations of energy transportation, economic development, and political stability as they pertain to regional energy supply. In disaster relief

operations, transportation plays a vital role in delivering essential supplies to affected areas. Deploying energy-efficient vehicles, such as electric or hybrid trucks, reduces fuel consumption and minimizes the environmental impact of relief efforts. According to Halldórsson and Kovács (2010), adopting energy-efficient transportation methods can significantly improve the efficiency of disaster relief logistics [9, 16, 17].

Furthermore, the integration of renewable energy sources into disaster management infrastructure enhances resilience and reduces dependency on centralized power grids. Solar panels, wind turbines, and micro-hydro systems can provide reliable energy supply to critical facilities like hospitals, emergency shelters, and water treatment plants. A study by Lee and Kim (2019) emphasizes that renewable energy systems contribute to the energy security of disaster-prone regions by providing decentralized and resilient power sources [18].

According to a study by Kibert et al. (2016), green building practices such as passive solar design, proper insulation, and efficient HVAC systems can significantly reduce energy consumption and minimize damage during disasters. Buildings constructed with energy efficiency in mind are better equipped to withstand extreme weather events, thereby safeguarding lives and property. Solar energy, in particular, has emerged as a key player in the transition to a low-carbon economy. Solar photovoltaic (PV) technology has witnessed rapid advancements, with falling costs and increasing efficiency driving widespread deployment. As noted in a study by Creutzig et al. (2017), solar PV has the potential to become the world's largest source of electricity by mid-century, providing a clean and abundant energy resource [19, 20].

Wind power is another renewable energy source that has experienced remarkable growth in recent years. Onshore and offshore wind farms have become increasingly competitive with conventional fossil fuel-based generation, offering a clean and scalable alternative. A report by the Global Wind Energy Council (GWEC) highlights that wind energy could meet over a third of global electricity demand by 2050, significantly reducing greenhouse gas emissions from the power sector. A paper studied from Mendecka and Lombardi (2019) suggests that expanding wind power capacity can

substantially reduce CO2 emissions from electricity generation and help mitigate climate change impacts [21, 22].

Hydropower, despite its environmental considerations, remains a significant contributor to renewable energy generation worldwide. Large-scale hydroelectric projects, as well as small-scale run-of-river and pumped-storage schemes, provide reliable and dispatchable electricity. However, sustainable hydropower development is crucial to minimize negative impacts on ecosystems and local communities. According to research by Gemechu and Kumar (2022), maximizing the climate mitigation potential of hydropower requires balancing environmental and social considerations. As per a 2022 study by Fang et al., hydropower can significantly contribute to the shift towards a low-carbon energy future, given that environmental and social factors are taken into account [23, 24].

Geothermal energy offers a reliable and continuous source of renewable power, with the potential to play a significant role in decarbonizing heating and cooling systems. Enhanced geothermal systems (EGS) and direct-use applications utilize heat from the Earth's crust for various energy needs. That "geothermal energy can provide baseload power and thermal energy with minimal greenhouse gas emissions, contributing to climate change mitigation efforts" is highlighted in the research by Tester et al. (2016). A study by Goff and Grigsby (2020), expanding geothermal energy utilization can contribute to reducing reliance on fossil fuels and mitigating climate change impacts [25, 26].

For instance, energy-efficient lighting systems and appliances in emergency shelters can prolong the operational duration of backup power systems, reducing the need for frequent refueling or maintenance. This not only conserves resources but also enhances the comfort and safety of displaced individuals during times of crisis. Moreover, the integration of energy-efficient transportation systems into disaster management plans can facilitate swift and efficient evacuation and relief operations. According to research conducted by Broaddus and Hardee (2017), incorporating electric or hybrid vehicles into emergency fleets can reduce fuel costs and emissions

while improving mobility in disaster-affected areas. Energy-efficient transportation modes not only enhance logistical capabilities but also contribute to environmental sustainability [27, 28].

In addition to reducing greenhouse gas emissions, renewable energy deployment offers numerous co-benefits for climate adaptation and sustainable development. Distributed renewable energy systems enhance energy access in remote and underserved areas, improving resilience to climate-related disasters. According to a report by the World Bank, renewable energy technologies contribute to poverty alleviation and enhance the adaptive capacity of vulnerable communities to climate change impacts [29].

In the aftermath of disasters, energy-efficient technologies facilitate rapid recovery and reconstruction efforts. Portable solar-powered generators and energy-efficient construction equipment enable efficient debris removal and infrastructure repair in areas with damaged or disrupted power supply. As highlighted in a study by Zhao et al. (2023) deploying energy-efficient equipment accelerates the restoration of essential services and facilitates the rebuilding of resilient communities [30].

Furthermore, the renewable energy sector drives innovation, job creation, and economic growth, fostering a transition to a more sustainable and inclusive economy. Investments in renewable energy projects spur technological advancements and drive down costs, making clean energy solutions increasingly accessible. A study in the Energy Policy journal emphasizes that the renewable energy sector offers significant opportunities for green job creation and economic development, particularly in emerging markets [31].

Policy support and regulatory frameworks play a crucial role in accelerating the deployment of renewable energy technologies and achieving climate targets. Governments around the world need to implement ambitious renewable energy policies, such as feed-in tariffs, renewable portfolio standards, and carbon pricing mechanisms, to incentivize investments and drive market transformation. As highlighted by the International Renewable Energy Agency (IRENA), Policy certainty and long-term commitments are essential for unlocking the full potential of renewable

energy deployment and driving the transition to a sustainable energy future. According to a policy brief by the UNDP, "Policy interventions that promote energy efficiency can strengthen the resilience of communities and contribute to sustainable development goals. Community resilience relies heavily on access to reliable and efficient energy services during and after disasters. Implementing decentralized energy systems, such as community microgrids and solar-powered charging stations, empowers local communities to maintain essential services and communication networks autonomously. The research published from Kammen and Sunter (2016) emphasizes that community-owned energy projects enhance resilience by fostering self-sufficiency and social cohesion [32-34].

2.3. Energy Efficiency In Disaster Areas

The most effective renewable energy sources for powering disaster relief efforts include solar energy, wind energy, and hybrid systems that integrate both. Solar electric vehicles (SEVs) equipped with vehicle-integrated photovoltaics (VIPV) can provide essential energy donations in disaster zones, enhancing resilience despite challenges in energy supply predictability. Mobile renewable energy systems, such as the Mobile Renewable Response Trailer (MRRT), utilize solar and wind energy to deliver reliable, zero-emission electricity for critical needs like medical equipment and communication. Additionally, plug-and-play microgrid systems can rapidly connect existing renewable energy sources and storage to provide emergency power, demonstrating flexibility in disaster scenarios. A microgrid is usually comprised of small units of renewable energy sources, battery storage, combined heat and power (CHP) plants and most importantly, an energy management system (EMS). The stand-alone power system has the advantage to operate independently from the grid; can be used as back up to the grid; provide energy security in case of natural disasters and storms; and also reduces the losses for the transmission lines. Solar PV systems have also been shown to meet significant energy demands in relief camps, achieving high performance ratios throughout the year. Overall, solar panels

emerge as the dominant technology, particularly when combined with microgrid solutions, to optimize cost and utility in disaster relief planning [35-39].

One area where energy efficiency plays a pivotal role is in the deployment of emergency response systems. Utilizing energy-efficient technologies in communication systems, such as satellite phones and renewable energy-powered base stations, ensures continuous connectivity during disasters. According to a study by Jones and Brown (2018), energy-efficient communication systems are essential for effective coordination and response during emergencies [40].

Despite the numerous benefits of renewable energy, challenges remain in scaling up deployment and overcoming barriers to adoption. Issues such as intermittency, grid integration, and financing constraints need to be addressed to maximize the potential of renewable energy in mitigating climate change. Advances in energy storage technologies, grid infrastructure, and supportive policies are essential for overcoming these challenges. According to a report by the IRENA, policy frameworks that promote renewable energy deployment and incentivize investment are crucial for achieving climate mitigation targets [41].

Furthermore, international cooperation and collaboration are key to accelerating the transition to renewable energy globally. Initiatives such as the Paris Agreement and the Sustainable Development Goals provide frameworks for countries to work together towards common climate objectives. By sharing knowledge, technology, and best practices, nations can accelerate the deployment of renewable energy and achieve collective emissions reduction targets. As highlighted in a study (2015), multilateral cooperation is essential for addressing climate change effectively and ensuring a sustainable energy future [42].

Information and communication technologies (ICTs) are indispensable tools in disaster preparedness and response. By utilizing energy-efficient ICT solutions, such as cloud computing and virtualization, organizations can optimize resource utilization and enhance the scalability of disaster management systems. According to a report by the International Telecommunication

Union (ITU), energy-efficient ICT infrastructure reduces operational costs and improves the reliability of communication networks during emergencies [43].

Beyond electricity generation, renewable energy solutions extend to sectors such as transportation, heating, and industry, where decarbonization efforts are equally crucial for addressing climate change. Electric vehicles (EVs), powered by renewable electricity, offer a promising alternative to internal combustion engine vehicles, reducing emissions from the transportation sector. A report by IEA indicates that electrifying transportation with renewable energy can significantly contribute to achieving climate targets and improving air quality [44].

In the heating sector, transitioning from fossil fuel-based systems to renewable heating technologies such as solar thermal, biomass, and heat pumps can significantly reduce carbon emissions and fossil fuel dependency. According to a study, widespread adoption of renewable heating solutions is essential for achieving deep decarbonization of the building sector and combating climate change [45, 46].

Moreover, renewable energy plays a critical role in industrial processes, where emissions reduction and energy efficiency improvements are paramount for mitigating climate change. Renewable electrification, coupled with energy-efficient technologies and processes, can help decarbonize energy-intensive industries such as steel, cement, and chemicals. The researches published from Yang et al. (2021) and Strielkowski et al. (2021) emphasize that integrating renewable energy into industrial production processes is essential for achieving carbon neutrality and combating climate change [47, 48].

In conclusion, renewable energy represents a fundamental solution for addressing climate change by reducing greenhouse gas emissions, enhancing energy security, and promoting sustainable development. Through continued innovation, investment, and international cooperation, the world can transition towards a low-carbon future powered by renewable energy.

3. CONCLUSION

Energy efficiency is a cornerstone of effective disaster management, encompassing various aspects from emergency response systems to infrastructure resilience. By leveraging energy-efficient technologies and adopting sustainable practices, communities can enhance their capacity to withstand and recover from disasters, ultimately fostering resilience and sustainable development.

The study results are summarized as follows:

- Different Natural disasters and different energy sources directly affect the energy consumption rate during the disaster process.

- In the context of disaster response, energy-efficient technologies play a vital role in ensuring the availability of critical services and infrastructure.

- Implementing energy-efficient building designs can mitigate the impact of disasters on infrastructure and enhance the resilience of communities.

- Solar energy, in particular, holds immense potential as a clean and abundant source of renewable power. Advances in photovoltaic technology have led to substantial cost reductions, making solar energy increasingly competitive with conventional fossil fuels. But when solar energy is introduced, disaster zones confront additional governance issues. For a more just and locally driven transition to renewable energy, strong subnational governance is essential.

- Wind energy is another renewable resource that plays a vital role in combating climate change. Onshore and offshore wind farms harness the kinetic energy of wind to generate electricity without emitting greenhouse gases or pollutants.

- Hydropower remains the largest source of renewable electricity worldwide, providing reliable and low-carbon energy to millions of people. While large-scale hydropower projects have faced criticism due to their environmental and social impacts, smaller-scale run-of-river and micro-hydropower systems offer sustainable alternatives with minimal ecological footprint.

- Geothermal energy, although less prominent compared to solar and wind power, offers a reliable and continuous source of renewable heat and electricity. Geothermal power plants tap into the Earth's natural heat reservoirs to generate electricity with minimal greenhouse gas emissions.

- Policy frameworks play a crucial role in promoting energy efficiency in disaster management. Governments and international organizations need to incentivize investments in energy-efficient technologies and incorporate energy considerations into disaster risk reduction strategies. Furthermore, in regions that are vulnerable to disasters, energy-efficient building designs are crucial. Passive design techniques, such as adequate insulation, open ventilation, and energy-efficient lighting, not only save energy usage but also strengthen a structure's resistance to severe weather.

In conclusion, renewable energy stands as a cornerstone in the fight against climate change, offering a viable pathway to decarbonize energy systems and mitigate greenhouse gas emissions. By harnessing the power of solar, wind, hydro, and geothermal energy, societies can foster a sustainable energy transition, enhance resilience to climate impacts, and build a cleaner and more prosperous future for generations to come.

On the basis of these results, we suggest that governments should put large-scale policies and programs into place in order to promote the creation of green technologies and concepts based on renewable energy. Furthermore, in order to increase renewable energy even further, environmental policies such as a carbon tax, investments in green technologies, subsidies, and incentives for infrastructure investments in renewable energy sources should be considered. Highlighted by this study integrating energy efficiency into disaster management is essential for building resilient and sustainable communities. By leveraging renewable energy sources, implementing energy-efficient building designs, optimizing critical infrastructure, and fostering collaboration among stakeholders, societies can enhance their ability to withstand and recover from disasters. However, realizing the full potential of energy efficiency in disaster management

requires concerted efforts, innovative solutions, and strategic partnerships at the local, national, and global levels.

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