

Review Article

Green Technology for Sustainable Disaster Management and Recovery

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A B S T R A C T

Natural catastrophes are becoming more frequent and intense, endangering populations throughout the world and necessitating creative and long-lasting approaches to disaster relief and recovery. The integration of green technologies is examined in this review paper as a cogent strategy to address these issues. The primary goals are to evaluate the state of disaster management procedures as they exist today, examine the possibilities of green technology, and provide a structure for integrating them. This review paper's methodologies include a thorough examination of the body of research, case studies, and instances of effective green technology applications in crisis management. Highlighting the beneficial effects of green technologies on mitigating environmental degradation, boosting resilience, and guaranteeing a more sustainable recovery process, the study summarises its main conclusions. Reducing the environmental impact of disaster response operations is largely dependent on the use of green technology, which includes enhanced monitoring systems, renewable energy sources, and environmentally friendly building materials. This paper promotes the use of green technology integration as a pillar of environmentally friendly disaster relief and management.

Keywords: Green Technology, Environmentally, Sustainable, Disaster, Management

Introduction

It is more important than ever to implement sustainable disaster management and recovery techniques in an era marked by the increasing effects of climate change and a rise in the frequency and intensity of natural catastrophes. In addressing the aftermath of natural disasters like hurricanes, floods, wildfires, and earthquakes, the world community is facing never-before-seen obstacles. It is becoming clear that the traditional methods of managing disasters, which are frequently marked by resource-intensive procedures and a propensity to worsen environmental damage, are inadequate for dealing with the increasingly complex

issues surrounding these crises. The incorporation of green technologies stands out in this context as a ray of hope and a paradigm-shifting force that is changing catastrophe management approaches. The idea of sustainability in disaster response recognises the connection between environmental health and community resilience to disasters, making it both a practical necessity and an ethical consideration. Green technology, which includes everything from eco-friendly building materials and monitoring systems to renewable energy solutions, has the potential to bring about a new era in which disaster management efforts and the ecosystems they aim to safeguard can coexist peacefully.¹

This comprehensive examination aims to accomplish multiple goals. In order to achieve this, it must first thoroughly analyse the condition of disaster management procedures as they exist today, looking closely at their advantages, disadvantages, and ecological effects. Second, by examining the unrealized potential of green technologies, the review aims to clarify how they might both mitigate the negative consequences of disasters on the environment and strengthen communities against their disastrous repercussions. Third, this paper aims to create a coherent framework for the incorporation of green technologies into conventional disaster management and recovery techniques by combining data from many sources, such as scholarly research and case studies. It explores the complex interactions that exist between the demands of policy, socioeconomic factors, and the complex web of ecological systems. Understanding the symbiotic relationship between green technologies and disaster resilience becomes increasingly important as the need for sustainable practices grows. Thus, this analysis offers a comprehensive investigation that blends theoretical understanding with real-world applications to map out a path towards a future in which peace reigns even in the aftermath of catastrophe.²

Literature Review

Societal resilience has always depended on disaster management and recovery, with a wealth of research examining these vital areas from many angles. The research shows that the environment is changing due to a combination of anthropogenic and natural influences; therefore, techniques for dealing with the problems caused by catastrophes need to be continuously reevaluated. The shortcomings of traditional disaster management techniques are a common issue in the literature. Conventional approaches frequently have a reactive, centralised structure that prioritises quick fixes above long-term durability. Research indicates that these methods often increase vulnerabilities and unintentionally contribute to environmental damage, especially when disasters brought on by climate change are involved. Recurring themes highlight the critical need for a paradigm shift towards sustainable practices and the relationship between ecological health and community resilience.

The socio-economic aspects of catastrophe management, which are frequently disregarded, present intrinsic challenges to current paradigms. The literature highlights the differences in resilience and vulnerability within communities, highlighting the significance of equitable approaches that take into account the particular requirements of various groups. The fragmented character of disaster response operations is another common criticism, which calls for a more integrated and

interdisciplinary strategy to handle the complex effects of disasters. The incorporation of environmentally friendly technologies becomes a central theme in the literature, indicating a possible remedy for the drawbacks of traditional disaster management. Research demonstrates the revolutionary effect of renewable energy sources in minimising the carbon footprint connected with disaster response, guaranteeing a steady supply of electricity during emergencies, and lowering reliance on non-renewable resources. To further improve structural resilience while reducing environmental effects, creative architectural concepts and environmentally friendly building materials are investigated. Numerous eminent studies examine the use of data, artificial intelligence, and sophisticated monitoring systems in disaster management. Data-driven decision-making processes, effective resource allocation, and more precise and fast early warning systems are all potential benefits of these technologies. The research shows how important technology may be for both anticipating and proactively lessening the effects of calamities. The literature study concludes by highlighting how crucial it is to use sustainable approaches in catastrophe recovery and management. It highlights the drawbacks of conventional methods and the urgent need to use green technologies as the basis for robust and environmentally responsible tactics. The review's synthesis of the body of literature lays the groundwork for a thorough comprehension of the issues at hand and opens the door for the parts to follow, which will examine various frameworks and solutions.^{3,4}

Green Technologies in Disaster Management

Clean, sustainable, or "green" technology refers to a broad range of inventions intended to solve environmental issues while advancing social and economic sustainability. It is an example of a comprehensive strategy meant to reduce the harm that human activity does to the environment. Sustainable building materials, intelligent infrastructure, waste management techniques, and renewable energy sources are some of the main elements of green technology. With their robust and sustainable solutions, these technologies play a crucial role in disaster management and recovery. The following sections go into further detail about particular categories of green technology, including case studies that demonstrate their efficacy and an examination of their applications in disaster-prone areas. Our goal is to create a path for the peaceful coexistence of environmental sustainability, technological innovation, and community resilience by incorporating these green technologies into disaster response techniques.

Renewable Energy

Because they embrace sustainable energy solutions, green technologies have a revolutionary impact on disaster management. Solar, wind, and hydropower stand out

among the popular choices as vital means of guaranteeing a steady supply of electricity both during and after calamities. Using the sun's limitless energy, solar panels provide off-grid solutions that enable communities to maintain vital services and communication lines even in the absence of a centralised power infrastructure. Solar power is especially useful in disaster-prone areas because of its adaptability, which makes it possible to install microgrids and portable solar systems that improve resilience locally. The renewable energy landscape is further diversified by wind turbines and hydroelectric systems, which offer decentralised energy-producing possibilities. These technologies provide a more robust and decentralised grid option during times of crisis, when centralised grids are vulnerable to disruption. Hydropower systems use the energy of flowing water, whereas wind turbines use the kinetic energy of the wind to generate steady, renewable electricity. In addition to ensuring a stronger reaction to emergencies, decentralisation of energy generation also promotes long-term community self-sufficiency. The real-world effects of integrating renewable energy technologies in disaster-prone areas are illustrated through case studies. One particularly interesting example of how localised solar power solutions. By providing a dependable energy supply for vital utilities, emergency services, and communication networks, these microgrids help communities better prepare for and recover from natural catastrophes. In summary, renewable energy is essential to the goal of sustainable disaster management because it gives communities dealing with environmental difficulties a method to become more resilient and self-sufficient.⁵

Eco-Friendly Construction

One of the most important ways to maximise the environmental impact of infrastructure while also enhancing structural resilience is to incorporate eco-friendly building materials and design ideas. This paradigm shift places a focus on sustainable resources like bamboo and repurposed steel. These types of materials are more resilient to seismic activity and severe weather, which is important in areas that are vulnerable to disasters and where infrastructure resilience is critical. By lowering a building's carbon footprint and increasing its durability, the use of these materials helps construction methods be more in line with larger environmental sustainability objectives. Green walls and roofs are extra components of environmentally friendly buildings that help reduce the impact of the urban heat island and increase energy efficiency. Vegetable-adorned green roofs act as natural insulation, lowering the amount of energy required for heating and cooling. They avoid floods and improve water conservation at the same time by absorbing rainfall and reducing storm water runoff. Likewise, green walls enhance air quality and regulate temperature, highlighting the comprehensive benefits of

environmentally friendly building methods that go beyond structural concerns. Eco-friendly construction methods have proven successful in disaster-prone places; there are many success stories to support this claim. These accounts demonstrate shorter recovery times following disasters and less damage to infrastructure. The resilience inherent in structures built using sustainable materials is especially apparent when confronted with the ever-changing difficulties presented by natural disasters. The use of resilient and sustainable building techniques not only safeguards people and property but also advances the more general objective of developing ecologically aware and adaptable urban settings by promoting disaster-resistant communities. Sustainable disaster management essentially revolves around eco-friendly construction, which harmonises the built environment with ecological considerations for a future that is more resilient and ecologically sensitive.^{6,7}

Waste Management

Effective waste management becomes essential to the integration of green technologies in disaster-prone locations as it addresses the environmental effects of quick reaction and recovery operations. Large volumes of waste are usually generated in the wake of disasters; therefore, finding creative ways to reduce the environmental impact of disposal is essential. In order to promote resilience and environmental stewardship, sustainable waste management strategies must be included because traditional trash disposal methods frequently worsen ecological damage. Technologies for recycling are essential in this situation because they provide a way to turn garbage produced by disasters into useful resources. Recycling reduces the amount of waste that ends up in landfills and preserves important resources by sorting and processing things like paper, metals, and plastics. By transforming organic waste into energy sources, waste-to-energy technologies further improve sustainability by assisting in the reduction of waste and the production of renewable energy. By using these technologies in places that are vulnerable to natural disasters, waste management procedures can be in line with more general environmental objectives, turning the aftermath of events into a chance for resource recovery. The effective application of creative waste management techniques is demonstrated by case studies in post-disaster circumstances. The studies emphasise the noteworthy accomplishment of reducing landfill utilisation and demonstrate how using green technologies can mitigate the environmental impact of garbage disposal. Resilient communities that are able to manage garbage in an environmentally conscious way are those that implement sustainable waste disposal measures, such as composting and decentralised recycling facilities. At the intersection of environmental sustainability and disaster response, waste

management becomes crucial. The integration of green technology in this field not only tackles the pressing issue of waste management but also advances the more general objectives of resource preservation, the production of renewable energy, and the development of communities that are robust to natural disasters. Disaster-prone places can turn the trash load into a chance for sustainable growth and environmental stewardship by adopting these innovations.⁸

Smart Infrastructure

The development of smart infrastructure, which makes use of data, artificial intelligence (AI), and sophisticated monitoring systems to improve the responsiveness and resilience of communities under threat from disasters, marks a revolution in disaster management. High-tech sensors that offer current environmental conditions are the foundation of smart infrastructure. Natural disaster early warning systems, which provide communities with critical time to prepare and escape, are made possible in large part by these sensors. Incorporating intelligent sensors guarantees a more prompt and focused reaction to new dangers while also increasing the precision of risk evaluations. The field of smart infrastructure relies heavily on artificial intelligence, which makes data-driven decision-making and predictive modelling possible. Artificial intelligence (AI) programmes examine enormous amounts of information to find trends, evaluate risks, and forecast the possible effects of disasters. By optimising resource allocation, this proactive method makes sure that response efforts are strategically focused on higher-risk locations. In addition to increasing emergency response efficiency, the application of AI in disaster management helps communities become more resilient overall and minimise damage. Several case studies carried out in disaster-prone areas demonstrate the efficacy of smart infrastructure. These studies offer concrete illustrations of how proactively managing risks, minimising losses, and enhancing community resilience are all made possible by the integration of new technologies. Smart infrastructure shows its value in a variety of crisis scenarios, from the deployment of AI-powered decision support systems to the predictive modelling of storm surge impacts. These success stories highlight how technology may revolutionise disaster management and highlight the necessity of ongoing investments in smart infrastructure to create communities that are more resilient and adaptive. The emergence of smart infrastructure represents a turning point in disaster management, providing a change in perspective from reactive to proactive approaches. Communities may more efficiently prepare for, respond to, and recover from disasters thanks to smart infrastructure, which combines artificial intelligence, real-time data, and cutting-edge

monitoring systems. Lessons from case studies highlight the transformative influence of smart infrastructure on the goal of catastrophe resilience and open the door for wider implementation.

Environmental Sustainability in Disaster ReCovery

Conventional disaster recovery techniques frequently place a strong emphasis on resource-intensive and environmentally harmful procedures. Large-scale building initiatives, the use of non-renewable energy sources, and the disposal of waste all contribute to rising carbon emissions and environmental deterioration. For example, the extensive use of fossil fuels in heavy machinery operation and material delivery in transportation exacerbates air pollution, further endangering ecosystem health. Furthermore, using traditional building supplies and methods can result in habitat degradation, soil erosion, and deforestation, which would increase the environmental impact of recovery efforts. Understanding these difficulties is essential to determining whether switching to more environmentally friendly methods of disaster recovery is necessary. Green technology's incorporation into disaster recovery represents a paradigm shift in favour of environmentally benign and sustainable methods. Reliance on fossil fuels can be decreased by using renewable energy sources, such as wind and solar power, to supplement or replace conventional energy systems. Recycled or locally sourced building materials are examples of sustainable building materials that not only reduce their negative effects on the environment but also help to create circular economies. Buildings with low energy consumption and intelligent waste management systems are examples of smart infrastructure that is essential to the development of resilient and sustainable communities. Additionally, integrating green technologies into transportation lowers carbon emissions and promotes a more ecologically responsible rehabilitation process.

The benefits of incorporating green technology into disaster recovery are demonstrated by a number of success stories. Resilient and environmentally friendly architecture has been shown to endure extreme weather events in locations vulnerable to hurricanes and typhoons. Recoveries have been faster, and energy resilience has grown in communities using localised renewable energy solutions. Sustainable recovery initiatives have shown us the value of community involvement and education in creating a sustainable environmental culture. Furthermore, the effective implementation of green recovery efforts has been largely attributed to cooperative collaborations between governments, non-profit groups, and the commercial sector. These triumphs highlight the viability and advantages of using green technology in disaster recovery procedures

and encourage further efforts towards more robust and sustainable results.

Challenges Take Place in Disaster Management

There are several obstacles and hurdles that prevent the easy use of green technology in disaster management. First and foremost, money is a major obstacle because adopting green technologies might be seen as having excessive upfront expenditures. Investment in sustainable solutions may be resisted by decision-makers, particularly in areas that are already experiencing economic hardship. Secondly, insufficient knowledge and comprehension among relevant parties, such as policymakers, may impede the efficient use of environmentally friendly technology. Insufficient understanding of the advantages and uses of these technologies could cause resistance or distrust. Moreover, regulatory obstacles that hinder innovation and impede integration include antiquated rules and the lack of incentives for eco-friendly behavior. To overcome these obstacles, a thorough grasp of the particular hurdles must be developed, along with focused tactics to address them.^{9,10}

Challenges

High upfront costs discourage green tech investment; implement subsidies and low-interest loans.

Stakeholders lack awareness of the benefits of the benefits of green technology; launch educational campaigns and training programmes.

Outdated regulations hinder green tech adoption; advocate for policy changes and incentives.

Existing infrastructure may not be compatible; develop transition plans and retrofitting strategies.

Lack of interoperability between green technologies; establish standards for seamless integration.

Stakeholders may be risk-averse to new technology; conduct pilot projects and share success stories.

Ensure green infrastructure resilience to disasters; invest in climate-resilient design principles.

Limited availability of key resources; explore alternative, sustainable materials and technologies.

Rapid technological advancements may lead to obsolescence; establish flexible and upgradable systems.

Community resistance to changes in practices; engage communities, address concerns, and demonstrate benefits.

Future Directions in Green Disaster Management

Promising paths for improving sustainability and resilience in the face of mounting climate-related concerns are presented by emerging trends and technology in green disaster

management. An important development in catastrophe prediction and response is the use of artificial intelligence (AI) and machine learning technologies. With the help of these technologies, disaster management organisations can make deft decisions quickly thanks to improved forecasting, early warning systems, and real-time data processing. Another important development is the combination of satellite imaging, Internet of Things (IoT) devices, and sophisticated sensor networks. These technologies offer an abundance of information for tracking environmental conditions, estimating damage, and organising effective response activities. Disaster management may become more proactive and responsive by utilising the potential of connected devices, reducing the impact on impacted populations. Furthermore, the future of green catastrophe management is still being shaped by the advancement of renewable energy alternatives. Resilient off-grid energy systems are being developed thanks to developments in energy storage and solar and wind technology. In order to support emergency response efforts, provide a steady supply of electricity during disasters, and aid impacted populations, these systems are essential.

Technological Innovations in Green Disaster Management

Technological developments have been a major factor in changing the face of green catastrophe management in recent years. Modern technologies have become effective instruments for improving response, recovery, and readiness to environmental hazards. The incorporation of artificial intelligence (AI) into disaster management systems is a noteworthy advance. Artificial intelligence (AI) enables authorities to forecast possible disasters and strategically allocate resources by facilitating predictive modelling and risk assessments. In order to increase early warning system accuracy, minimise the impact of disasters, and give communities timely notifications, machine learning algorithms examine previous data. Data collection and monitoring during catastrophes have been transformed by the Internet of Things (IoT). IoT allows for the deployment of a network of networked sensors and devices, allowing for the real-time collection of data on a variety of environmental characteristics, including temperature, humidity, and seismic activity. This abundance of information improves situational awareness, enabling emergency personnel to act quickly and decisively. IoT devices also improve communication between various disaster management infrastructure components, guaranteeing a well-coordinated and effective response. In addition, Geographic Information System (GIS) technology has emerged as a vital resource for green disaster management. It allows for the mapping and visualisation of disaster-prone areas, vital infrastructure, and evacuation routes. By combining spatial data, authorities can create efficient evacuation plans, strategically allocate resources,

and evaluate the environmental effects of disasters. This technology encourages critical thinking and strengthens resilience overall.¹¹

Advancements in Artificial Intelligence, IoT, and Other Technologies for Efficient Disaster Response and Recovery

The Internet of Things, artificial intelligence, and other technical advancements all greatly increase the effectiveness of disaster response and recovery procedures and can prioritise locations that require immediate care by using AI-powered image identification and analysis to help with speedy damage assessment. Real-time imagery of disaster-affected areas is provided by drones fitted with AI algorithms and sensors, which helps with damage assessment and search and rescue efforts. One additional significant advancement is the incorporation of robotics. Unmanned ground vehicles and aerial drones are examples of robotic devices that can access dangerous or difficult-to-reach areas and help in the search for survivors and the delivery of necessary supplies. These technologies speed up recovery efforts and improve reaction team safety. Additionally, improvements in communication technologies—like mobile applications and satellite connectivity—allow emergency teams to coordinate more effectively and give impacted communities access to vital information. Resource allocation, evacuation routes, and emergency notifications are made easier by mobile app capabilities. The combination of IoT, GIS, AI, and other technological advancements gives disaster management initiatives previously unheard-of powers. In addition to improving response and recovery times and precision, these technologies help communities become more resilient to the effects of climate change and an increase in the frequency of natural disasters.

Conclusion

The significance of environmental sustainability in the recovery phase has been emphasised, highlighting the ecological consequences of traditional recovery techniques and the potential of green solutions to reduce environmental damage. Financial limitations, a lack of awareness, and regulatory obstacles were revealed as the difficulties in integrating green technology into disaster management were explained. Proposed solutions to these issues include financial mechanisms, policy advocacy, and educational initiatives. These strategies emphasise the need for proactive steps to lay the groundwork for sustainable disaster management procedures. Future directions for disaster management are bright thanks to new developments in artificial intelligence (AI), the internet of things (IoT), and circular economy concepts. To ensure that disaster management stays adaptive and effective in the face of changing difficulties, future research and development should focus on resilient infrastructure design

and developments in eco-friendly transportation systems. The integration of AI, IoT, and GIS technologies in disaster management enables effective response plans and gives decision-makers access to fast and precise information that is essential for mitigating the effects of disasters.

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