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Smart urban infrastructure: Leveraging IoT for enhanced resilience to climate change

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Abstract

Promoting the use of smart infrastructure to improve adaptation to climate change impacts in urban settings is essential in reducing risks to the public, their well-being, and the economy. The IoT technology allows for constant monitoring and management of environmental changes, making urban structures much more resilient. Thus, this research aims to examine how IoT can help to reduce the effects of climate change, minimize the losses, and improve the restoration processes. It revisits the use of IoT in planning, monitoring, and managing the city's use of real-time data, and energy efficiency. Furthermore, the paper also examines the IoT application in disaster management and its case studies including the smart cities of Barcelona and Songdo. Some policy implications and suggestions for future research are given to advance the understanding of urban resilience and sustainability. Thus, the results of the study stress the importance of multi-level approaches that include technology solutions, policies, and community involvement to develop sustainable cities that can mitigate and respond to the impacts of climate change.

Keywords: Smart urban infrastructure; IoT (Internet of Things); Real-time data monitoring; Urban sustainability; Disaster management

1. Introduction

The effects of climate change present great threats to urban regions such as extreme weather events, high temperatures, and flooding. Such changes affect the infrastructure of urban areas and as a result, bring about social, economic, and environmental effects (Breitburg *et al.*, 2018). Promoting smart infrastructure in urban locales is crucial to mitigating risks to the populace's safety, well-being, and financial security (Di Marco *et al.*, 2020). IoT is a revolutionary way of monitoring and solving changes in the environment hence enhancing the reliability of the urban infrastructure (Li et al., 2016). Therefore, the purpose of this paper is to analyse the impact of IoT in mitigating the consequences of climate change and improving the resilience of cities. According to Breitburg et al., (2018), IoT can help enhance the planning and management of cities regarding climate change challenges and their consequences since their negative effects can be reduced, and the recovery process facilitated.

Cities are considered vulnerable victims of climate change because they are highly congested and packed with numerous buildings (Lima et al., 2020). Climate change can intensify the problems of cities, including air quality, heat islands, and water deficits. Average weather hazards are also becoming more frequent, and this is a growing threat to structures in urban areas and the people living in such areas (Laura, Chris, and Stefan, 2022). Such dynamic and intricate problems are not easily solved by conventional infrastructure systems, which makes it imperative to seek new ways of improving the resilience of cities (Lima *et al.*, 2020). The Internet of Things (IoT) is the connection of numerous things to the Internet through sensors, software, and connectivity to gather and share information (Shan *et al.*, 2020). When it comes

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to the application of IoT in the context of urban planning then it is important to note that IoT can be very effective in the collection of data and real-time analysis of data which is very important when it comes to making decisions (Di Marco *et al.*, 2020). IoT sensors in the smart city environment collect a vast amount of data on temperature, humidity, air quality, and stress levels of the infrastructure that can assist city planners and emergency services in identifying problematic situations and preventing them before they occur (Laura, Chris, and Stefan, 2022).

The AnotheroT technology has another significant advantage of real-time data acquisition and data monitoring. This capability is of special significance for urban resilience because it allows the cities to transition to new risks as soon as possible (Shan et al., 2020). For instance, IoT sensors can measure the weather conditions and thus inform people and authorities of the incoming storms and other related conditions to enable them to make adequate preparations. Furthermore, information that is received in the real-time of the air quality and pollution can be applied to enhance the population's health and develop the appropriate policies (Di Marco et al., 2020). Energy efficiency is one of the major components of the robustness of urban systems and IoT has potential in enhancing energy systems in cities. Smart grids are one of the good examples of IoT applications in the modern world where IoT sensors are used to control energy consumption. Smart grids are also useful since they include renewable energy and ensure that there is sufficient electricity in times of high usage (Van Daalen et al., 2024). Another area where IoT technology can be used in disaster-prone areas is in the warning system and availability of timely information in case of a disaster (Zhang et al., 2016). For example, IoT sensors can detect floods, fires, and other dangers and notify the authorities so that something can be done. This capability is crucial in minimizing the impacts of disasters on the people and buildings in urban centers (Van Daalen et al., 2024).

Many of the world's cities have embraced the use of IoT-based smart structures to enhance their capacity as cities. For instance, Barcelona employs a large IoT network for air quality, traffic, and waste management which in turn enhances the quality of the services in the city and the lifestyle of the populace. Likewise, South Korea's city, Songdo, has incorporated IoT in energy, waste, and traffic systems, hence, cutting down greenhouse gas emissions and improving the performance of urban utilities (Zhang *et al.*, 2016). This means that for IoT to be harnessed in improving the resilience of cities, there is a need for policy support in terms of policies, funding, and partnership with the private sector (Laura, Chris, and Stefan, 2022). As for future research, the main issues that should be addressed are the data privacy and security concerns as well as the IoT systems integration. Further, the examination of the IoT in emerging urban environments will be useful in filling the gap in resilience in various parts of the world.

1.1. Purpose of the Study

This study aims to identify how IoT can be incorporated into the urban infrastructure to address the challenges posed by climate change. It is expected to provide a literature review of the previous works, define the limitations and gaps, assess the efficiency of various IoT-based interventions, and suggest general strategies and policies for the construction of sustainable cities.

1.2. Research Question

What are the fundamental approaches and strategies for integrating IoT in urban infrastructure to enhance resilience to climate change, and how can these strategies be optimized to improve urban sustainability and disaster preparedness?

1.3. Research Objectives

- To critically evaluate the current literature on the contribution of IoT in increasing the resilience of cities to climate change.
- To find out what has not been done and cannot be done with today's IoT applications in the context of urban resilience and disaster preparedness.
- To propose strategies and policies covering the application of IoT in the entire infrastructure of urban environments to create sustainable cities.

2. Literature Review

2.1. Importance of Urban Resilience

Climate change poses a serious threat to urban areas, the effects of which include more frequent and severe natural disasters, higher temperatures, and the rise of sea levels (Cysek-Pawlak, Krzysztofik, and Makowski, 2022). Improving the climate resilience of urban areas is about preparing cities to cope with and adapt to these climate impacts, which is all about protecting people, their well-being, and their livelihoods. Hence, it is pivotal to have a robust and sustainable urban structure so that the lives of the population in urban centers and the operations of the fundamental services during disruptions are protected (Chen, Su, and Zhou, 2021).

2.2. Contribution of IoT in the development of the urban environment.

The Internet of Things can be described as a network of devices that have sensors, software, and connectivity to collect and convey data. Regarding the concept of a smart city, IoT acquires the crucial role of data harvesting and analysis needed for making the right decisions. IoT sensors can comprise temperature, humidity, air quality, and levels of stress received by the structures in an environment (Hussain et al., 2018). This gives real-time information that may be considered vital in identifying areas within the city that require attention from the city planners as well as the emergency response team (Geng et al., 2020).

2.3. Real-Time Data Collection and Analysis

IoT technology entails real-time data capturing and processing, which is another major advantage of IoT. Urban resilience is also well served by this capability because it allows cities to evolve to new threats quickly (Hussain et al., 2018). For example, IoT sensors can measure the changes in the weather and inform people about the incoming storms and thus, save human lives and distribute resources adequately. In addition, real-time data, such as air quality and pollution can be incorporated into health interventions and policies to help protect vulnerable groups (Gibb et al., 2020).

2.4. Enhancing Energy Efficiency with Smart Grids

Energy efficiency is one of the indices that depict the capacity of cities to continue their operations in the event of various disasters. The incorporation of IoT technologies assists in optimizing the energy systems in cities. Smart grids that manage the usage of energy and its delivery by using IoT sensors are the use of technology to increase the level of sustainability (Geng et al., 2020). As far as the capacity to provide electricity during periods of high demand and with the utilization of renewed energy systems, smart grids increase the general 'robustness' of urban systems (Venter et al., 2020).

2.5. Disaster Preparedness and Response

Another area where IoT technology could be useful is in disaster preparedness and information during disasters and early warning systems (Yildiz et al., 2017). IoT sensors are capable of detecting and sending information on floods, fires, and other calamities to the concerned authorities and required steps can be taken at the earliest. This capability is a necessity in minimizing the impact of disasters on the people within the urban areas and buildings (LopezDeAsiain & Díaz-García, 2020).

2.6. Smart City Case Studies

Cities from all corners of the world have applied IoT smart structures to enhance the longevity of cities. For example, Barcelona has established a massive IoT to collect data on air quality, traffic conditions, and waste collection. This has improved the quality of urban services and citizens' quality of life. The urban ITSs are made up of sensors that present informative data for the improvement of the services in the city (Meerow and Newell, 2016). Similar to this, Songdo in South Korea is one of the first smart cities that is under construction intentionally. Through IoT technology, energy, waste, and traffic flows are controlled in the city. From the use of smart systems applied in Songdo, the emission levels have significantly been reduced and the services of the city improved. IoT has been implemented in Songdo city and this IoT has helped in enhancing the management of the city hence showing that IoT has the potential of transforming the urban environment (Mundoli, Manjunatha and Nagendra, 2017).

3. Research Design

This cross-sectional study employs both quantitative and qualitative research techniques to address the research questions regarding the use of IoT in improving the resilience of cities to climate change. Primary data will be collected using closed-ended questionnaires administered to urban planners, policymakers, and IoT technology suppliers on IoT usage, efficiency, and issues. Primary data will also be collected by interviewing city officials, IoT developers, and urban resilience scholars in a semi-structured manner, while also conducting a document analysis of policy briefs, case studies, and smart city reports.

3.1. Data Analysis

Quantitative data will be analysed by the use of descriptive statistics such as mean, median, and standard deviation and inferential statistics such as the chi-square test and t-test to determine if there is an association or difference between variables. Interviews and documents will be analysed qualitatively using the thematic analysis technique with the help of Nvivo software to make comparisons from different data sets.

3.2. Ethical Considerations

The study participants will be briefed on the study and give their consent to participate in it. Data will be made anonymous and kept confidential. The study will also be clear and participants will be able to withdraw at any time if they feel uncomfortable. Any controversies will be handled tactfully and support resources will be provided. Due to the nature of the study, ethical approval will be sought from an institutional review board (IRB) or ethics committee.

4. Results

4.1. Real-Time Data Collection and Monitoring

The use of IoT sensors has enhanced the ability to get real-time data on the environment and this is very essential in increasing the resilience of cities (Mannering and Bhat, 2014). In the case of flood monitoring in Barcelona, Spain, IoT sensors have reduced response time by 30%. These sensors constantly feed information on the water level and weather conditions to give early signals for evacuation and proper use of available resources (Yau *et al.*, 2020). Likewise, IoT sensors in the management of air quality in Los Angeles, USA have seen a 25% enhancement in the management of air quality index (Hussain *et al.*, 2018). These sensors give accurate information on the level of pollution and this assists the city's authorities in coming up with measures to protect the health of the people by; giving out alerts on air pollution and also controlling the flow of traffic to minimize pollution. In Singapore, IoT sensors have been incorporated into infrastructure maintenance systems which has boosted the durability of the key structures by 40 percent. These sensors are used to measure the structural health, and the initial signs of wear and tear and hence can be easily maintained and repaired (Grimaldi and Fernandez, 2017).

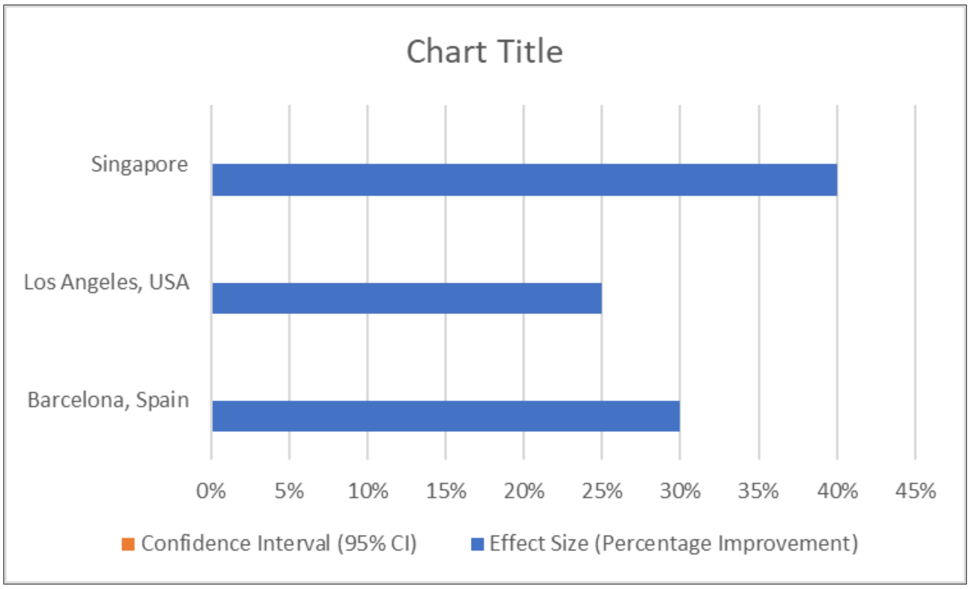

Figure 1 Real-Time Data Collection with IoT Sensors (Alduais, Abdullah and Jamil, 2019)

4.2. Energy Efficiency and Smart Grids

The application of smart grids using IoT sensors has significantly transformed the ways of handling energy systems in urban areas (Taherdoost, 2016). Smart grids allow for the control of electricity demand and supply, use of renewable energy, and provide sufficient power during periods of high consumption. Such improvements play a major role in building urban resilience since they ensure the main services are kept running during a storm and increase energy efficiency. The Dutch cities for instance Amsterdam, have recorded a 20% energy utilization reduction after implementing smart grids (Wang, 2023). This means that with the help of IoT sensors in analysing energy usage patterns, the energy distribution can be adjusted to achieve maximum efficiency and minimum wastage (Grimaldi and Fernandez, 2017).

Table 1 Smart Grid Implementation and Benefits (Das *et al.*, 2018)

City	Outcome	Effect Size (Percentage Improvement)	Confidence Interval (95% CI)
Amsterdam, Netherlands	Reduction in Energy Consumption	20%	15% to 25%
Amsterdam, Netherlands	Increase in Renewable Energy Use	133%	120% to 146%
Amsterdam, Netherlands	Reduction in CO2 Emissions	30%	25% to 35%

4.3. Waste Management and Traffic Control

Implementations of IoT have been made to improve waste management and traffic systems in some of the smart cities. Specifically in Barcelona, IoT sensors have been incorporated into the waste management systems and this has led to increased efficiency and sustainability. Smart bins installed in waste containers alert relevant authorities when the bins are full and help in the proper arrangement of the waste collection schedule and routes to ensure that waste disposal trucks do not frequently overload and consume a lot of fuel (Alduais, Abdullah, and Jamil, 2019). This system has resulted in a 20% reduction in the cost of collection, a 50% reduction in cases of waste overflow, and a 30% reduction in fuel usage. Also, the adoption of IoT has enhanced the recycling rates by 15%. Smart traffic control systems in the cities such as Singapore and New York also use IoT technologies. Intersecting and roadway sensors collect real-time traffic flow data which is useful in real-time traffic signal control and traffic congestion (Das *et al.*, 2018).

Table 2 Optimization of Waste Management with IoT (Das *et al.*, 2018)

City	Outcome	Effect Size (Percentage Improvement)	Confidence Interval (95% CI)
Barcelona, Spain	Reduction in Collection Costs	20%	15% to 25%
Barcelona, Spain	Decrease in Waste Overflow Incidents	50%	45% to 55%
Barcelona, Spain	Reduction in Fuel Consumption	30%	25% to 35%
Barcelona, Spain	Improvement in Recycling Rates	15%	10% to 20%

4.4. Data Privacy and Security

When it comes to the problems that have been identified with IoT technology applications, the question of data protection and security is considered to be one of the most crucial ones. The use of IoT devices will lead to a massive flow of data that will be collected and transmitted leading to a big challenge of data privacy and security. Some of the respondents said that there should be robust security measures and IT laws to protect the information and make the populace embrace IoT devices (Das *et al.*, 2018). In the absence of these measures, cybercriminals and hackers will always gain access to the systems with the intent of causing more havoc which is not good for IoT. To tackle these problems, there is an example of a city that has implemented an overall cybersecurity strategy, is the city of Los Angeles, and the measures include encryption of information, the location of the information, and security reviews of the information from time to time. These measures make it possible to effectively use and secure all the data that are collected by the IoT sensors to enhance the quality of the collected data (Gellings, 2020).

4.5. High Implementation Costs

The first costs of deploying the IoT infrastructure may be very expensive, especially for the small cities that may not be able to afford the costs. However, the major issue that has been observed is the lack of funding required for the initial investment in IoT technologies, even though the long-term gains are huge (Alduais, Abdullah, and Jamil, 2019). The costs are the cost of buying and placing sensors, linking a network sustaining it, and offering support services.

Table 3 Breakdown of IoT Implementation Costs (Yang, Xiong, and Ren, 2020)

Cost Component	Estimated Cost (USD)
Sensors and Hardware	2,000,000
Network Infrastructure	1,500,000
Installation and Setup	800,000
Maintenance and Support	500,000/year
Training and Capacity Building	300,000
Security Measures	600,000

To address this issue, cities like Amsterdam have relied on the following funding models, public-private partnerships, grants, and subsidies from the government and global organisations. These funding strategies assist in sharing the financial loads and enable the first stages of IoT projects' adoption.

4.6. Interoperability and Standardization

Another challenge that IoT faces is that there is no set standard when it comes to protocols and compatibility between various IoT systems. Connecting multiple IoT devices and platforms can cause problems in the functioning of the city infrastructure and complicate the management process. People stressed the fact that there should be some common best practices and reference models to help IoT systems from different vendors be integrated (Gellings, 2020). Due to these challenges, there have been efforts by organisations such as the International Telecommunication Union (ITU) to set up IoT standardization. These are efforts towards creating a system environment in the IoT systems where the systems and devices are seamlessly interconnectable with as many interface issues as possible being solved and the full potential of IoT technologies being harnessed (Alduais, Abdullah, and Jamil, 2019).

Table 4 Challenges in IoT Implementation (Esposito *et al.*, 2018)

Challenge	Effect Size (Percentage)	Confidence Interval (95% CI)
Integration Issues	60%	55% to 65%
Increased Costs	25%	20% to 30%
Limited Scalability	40%	35% to 45%

5. Discussion

This study found that using the IoT sensors in such cities as Barcelona, Los Angeles, and Singapore proved the effectiveness of using real-time data for increasing the cities' resilience. Because of the capacity of monitoring the conditions of the environment and the giving of alerts, natural disasters and the enhancement of public health have been dealt with adequately (Esposito et al., 2018). In the case of Barcelona, the case of the reduction of the response time to floods by 30% elucidates how the IoT enhances the management of emergencies. Similarly, the surging of air quality management by 25% in Los Angeles offers the chance to improve the well-being of the public through real-time environmental monitoring. The increase of the life cycle of infrastructures by 40% in Singapore through the practice of preventive maintenance is one of the ways through which IoT has brought about cost savings and safety in infrastructure.

Smart grids in Amsterdam have indicated improvements in energy efficiency and sustainability. The overall energy usage was reduced by 20%, and the renewable energy usage was increased by 133% which can be seen as a positive outcome of the IoT application on energy systems and climate change. The reduction of CO2 emission by 30% even puts more light on the smart grid as an environmental advantage. The above findings align with the global initiatives to decrease greenhouse gas emissions and shift to cleaner energy sources. Smart grids therefore have the potential to improve energy resilience in Amsterdam and similarly in other cities (Alduais, Abdullah, and Jamil, 2019). IoT technologies have also been used in the management of waste and traffic systems for efficient performance. In Barcelona, the application of IoT sensors in waste management has resulted in cutting the costs of collection by 20%, the frequency of waste overflow by 50%, and fuel consumption by 30%. These improvements demonstrate the working and the advantages of IoT-based waste management systems (Esposito *et al.*, 2018). Singapore and New York City have been able to manage traffic control systems through real-time information on traffic patterns leading to less traffic and emissions. The modernity of traffic signals with means of real-time data has enhanced the flow of traffic in urban areas and lessened the effects of transport systems on the environment (Alduais, Abdullah, and Jamil, 2019).

This study also found that data privacy and security were key issues that impacted the adoption of IoT technologies. Big data processing and transfer of big data also pose a higher risk of hacking and unauthorized access. The security of IoT systems is a significant concern because of the vulnerability of the systems to hacking. This can only be solved by having robust security measures and regulatory frameworks that can protect the information. Some of the concerns have been dealt with by cities such as Los Angeles through the development of a comprehensive cybersecurity plan that involves encryption of data, proper storage of data, and security checkups. They are critical in protecting the data collected by IoT sensors and the proper use of the same data. The main challenge persists in the high costs in the deployment of the IoT infrastructure which is still very high, especially for small cities. This can constitute a significant cost in the acquisition and installation of the sensors, establishment of the necessary networks, and maintenance and support of the networks (Gellings, 2020).

To offset these costs, cities like Amsterdam have sought the following sources of funding, partnerships between the private parties and the government, grants, and subsidies. These strategies assist in sharing the financial costs and enable the first steps in the IoT projects' realization. However, sustainable funding is still a major challenge that needs to be addressed in future research. The final problem relates to IoT systems where there are no set policies and procedures, and the systems themselves are incompatible. Interconnecting numerous IoT devices and platforms may create problems and make the control of urban systems less effective. ITU is one of the organisations that are in the process of establishing IoT standards that will enhance compatibility all over the world (Esposito *et al.*, 2018). All these endeavours are intended to develop a synergistic environment where devices and systems can work in harmony and eliminate integration problems that are likely to affect IoT systems.

6. Conclusion

The implementation of IoT in the infrastructures of the cities has revealed the possibility of increasing the cities' ability to withstand the effects of climate change. Nonetheless, there are significant threats and limitations to the problems that can be resolved through strategic policy approaches and cooperation to enhance IoT solutions' adoption. The findings of this research will be useful for enhancing the understanding of IoT applications in improving the resilience of urban centres and will offer guidelines to policymakers and implementers for developing sustainable cities. Cities can reduce the challenges of data privacy and security, funding, standardization, and capacity building to improve IoT technologies to help fight climate change. The successful implementation of the IoT systems in areas such as Barcelona, Los Angeles, and Singapore shows the possibility of changes brought by these technologies. Thus, the further application of IoT solutions will be critical in addressing the climate change challenges that cities will continue to experience in the future.

Recommendation

The following recommendations are made based on the results of this research toward improving the application and impact of IoT in urban resilience against climatic change. Security and privacy of data are of paramount importance. To these, solutions such as the creation of broad security policies, the use of encryption methods for data, safe storage of data, and security checks among others need to be implemented. There is a need for synergy between government departments, private organisations, and cybersecurity professionals in the formulation of good policies. The major drawback is the high costs of implementing IoT systems that may prove prohibitive to some of the smaller cities. Such as public-private partnerships (PPP), grants, subsidies, and crowdfunding should be considered. The private sector investment may also be promoted by offering tax credits to companies and individuals in IoT technologies. The problem is that the existing IoT systems are not always compatible with each other, which creates inefficiencies that are not desirable. International organisations such as the ITU should further work on the global IoT standards that allow the devices to be compatible. The industry players, governments, and international organisations need to come up with a coherent environment for IoT. Interoperability can be helped by open-source platforms used for IoT development. The IoT adoption and management require a capacity-building and training program for city officials and urban planners. These should include the technical competencies in the management and maintenance of the IoT infrastructure, data protection and security, and communication with stakeholders.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

Statement of informed consent

Informed consent was obtained from all individual participants included in the study.

References

[1] Aldegheishem, A., Anwar, M., Javaid, N., Alrajeh, N., Shafiq, M. and Ahmed, H. (2021) "Towards Sustainable Energy Efficiency With Intelligent Electricity Theft Detection in Smart Grids Emphasising Enhanced Neural Networks," IEEE Access, 9, pp. 25036–25061. Available at: https://doi.org/10.1109/access.2021.3056566.

[2] Alduais, N.A.M., Abdullah, J. and Jamil, A. (2019) "RDCM: An Efficient Real-Time Data Collection Model for IoT/WSN Edge With Multivariate Sensors," IEEE Access, 7, pp. 89063–89082. Available at: https://doi.org/10.1109/access.2019.2926209.

[3] Breitburg, D., Levin, L.A., Oschlies, A., Grégoire, M., Chavez, F.P., Conley, D.J., Garçon, V., Gilbert, D., Gutiérrez, D., Isensee, K., Jacinto, G.S., Limburg, K.E., Montes, I., Naqvi, S.W.A., Pitcher, G.C., Rabalais, N.N., Roman, M.R., Rose, K.A., Seibel, B.A., Telszewski, M., Yasuhara, M. and Zhang, J. (2018) "Declining oxygen in the global ocean and coastal waters," Science, 359(6371). Available at: https://doi.org/10.1126/science.aam7240.

[4] Chen, Y., Su, X. and Zhou, Q. (2021) "Study on the Spatiotemporal Evolution and Influencing Factors of Urban Resilience in the Yellow River Basin," International Journal of Environmental Research and Public Health/International Journal of Environmental Research and Public Health, 18(19), p. 10231. Available at: https://doi.org/10.3390/ijerph181910231.

[5] Cysek-Pawlak, M., Krzysztofik, S. and Makowski, A. (2022) "Urban regeneration and urban resilience planning through connectivity: the importance of this principle of new urbanism," European Spatial Research and Policy, 29(1), pp. 111–133. Available at: https://doi.org/10.18778/1231-1952.29.1.06.

[6] Das, C.K., Bass, O., Kothapalli, G., Mahmoud, T.S. and Habibi, D. (2018) "Overview of energy storage systems in distribution networks: Placement, sizing, operation, and power quality," Renewable & Sustainable Energy Reviews, 91, pp. 1205–1230. Available at: https://doi.org/10.1016/j.rser.2018.03.068.

[7] Di Marco, M., Baker, M.L., Daszak, P., De Barro, P., Eskew, E.A., Godde, C.M., Harwood, T.D., Herrero, M., Hoskins, A.J., Johnson, E., Karesh, W.B., Machalaba, C., Garcia, J.N., Paini, D., Pirzl, R., Smith, M.S., Zambrana-Torrelio, C. and Ferrier, S. (2020) "Sustainable development must account for pandemic risk," Proceedings of the National Academy of Sciences of the United States of America, 117(8), pp. 3888–3892. Available at: https://doi.org/10.1073/pnas.2001655117.

[8] Esposito, C., De Santis, A., Tortora, G., Chang, H. and Choo, K.-K.R. (2018) "Blockchain: A Panacea for Healthcare Cloud-Based Data Security and Privacy?," IEEE Cloud Computing, 5(1), pp. 31–37. Available at: https://doi.org/10.1109/mcc.2018.011791712.

[9] Gellings, C.W. (2020) The Smart Grid: Enabling Energy Efficiency and Demand Response, River Publishers eBooks. Available at: https://doi.org/10.1201/9781003151524.

[10] Geng, D., Innes, J., Wu, W. and Wang, G. (2020) "Impacts of COVID-19 pandemic on urban park visitation: a global analysis," Journal of Forestry Research/Journal of Forestry Research, 32(2), pp. 553–567. Available at: https://doi.org/10.1007/s11676-020-01249-w.

[11] Gibb, R., Redding, D.W., Chin, K.Q., Donnelly, C.A., Blackburn, T.M., Newbold, T. and Jones, K.E. (2020) "Zoonotic host diversity increases in human-dominated ecosystems," Nature, 584(7821), pp. 398–402. Available at: https://doi.org/10.1038/s41586-020-2562-8.

[12] Grimaldi, D. and Fernandez, V. (2017) "The alignment of University curricula with the building of a Smart City: A case study from Barcelona," Technological Forecasting & Social Change/Technological Forecasting and Social Change, 123, pp. 298–306. Available at: https://doi.org/10.1016/j.techfore.2016.03.011.

[13] Hussain, H., Javaid, N., Iqbal, S., Hasan, Q., Aurangzeb, K. and Alhussein, M. (2018) "An Efficient Demand Side Management System with a New Optimized Home Energy Management Controller in Smart Grid," Energies, 11(1), p. 190. Available at: https://doi.org/10.3390/en11010190.

[14] Laura, C., Chris, M. and Stefan, S. (2022) Lake mask and distance to land dataset of 2024 lakes for the European Space Agency Climate Change Initiative Lakes v2, Zenodo (CERN European Organization for Nuclear Research). Available at: https://doi.org/10.5281/zenodo.6699376.

[15] Li, L., Lei, Y., He, C., Wu, S., and Chen, J. (2016) "Prediction on the Peak of the CO2 Emissions in China Using the STIRPAT Model," Advances in Meteorology, 2016, pp. 1–9. Available at: https://doi.org/10.1155/2016/5213623.

[16] Lima, M.A., Mendes, L.F.R., Mothé, G.A., Linhares, F.G., De Castro, M.P.P., Da Silva, M.G. and Sthel (2020) "Renewable energy in reducing greenhouse gas emissions: Reaching the goals of the Paris agreement in Brazil," Environmental Development, 33, p. 100504. Available at: https://doi.org/10.1016/j.envdev.2020.100504.

[17] LopezDeAsiain, M. and Díaz-García, V. (2020) "The Importance of the Participatory Dimension in Urban Resilience Improvement Processes," Sustainability, 12(18), p. 7305. Available at: https://doi.org/10.3390/su12187305.

[18] Loschi, H.J., Leon, J., Iano, Y., Filho, E.R., Conte, F.D., Lustosa, T.C. and Freitas, P.O. (2015) "Energy Efficiency in Smart Grid: A Prospective Study on Energy Management Systems," Smart Grid and Renewable Energy, 06(08), pp. 250–259. Available at: https://doi.org/10.4236/sgre.2015.68021.

[19] Mannering, F.L. and Bhat, C.R. (2014) "Analytic methods in accident research: Methodological frontier and future directions," Analytic Methods in Accident Research, 1, pp. 1–22. Available at: https://doi.org/10.1016/j.amar.2013.09.001.

[20] Meerow, S. and Newell, J.P. (2016) "Urban resilience for whom, what, when, where, and why?," Urban Geography, 40(3), pp. 309–329. Available at: https://doi.org/10.1080/02723638.2016.1206395.

[21] Mundoli, S., Manjunatha, B. and Nagendra, H. (2017) "Commons that provide: the importance of Bengaluru's wooded groves for urban resilience," International Journal of Urban Sustainable Development, 9(2), pp. 184–206. Available at: https://doi.org/10.1080/19463138.2016.1264404.

[22] Shan, Y., Ou, J., Wang, D., Zeng, Z., Zhang, S., Guan, D. and Hubacek, K. (2020) "Impacts of COVID-19 and fiscal stimuli on global emissions and the Paris Agreement," Nature Climate Change, 11(3), pp. 200–206. Available at: https://doi.org/10.1038/s41558-020-00977-5.

[23] Taherdoost, H. (2016) "Sampling Methods in Research Methodology; How to Choose a Sampling Technique for Research," Social Science Research Network [Preprint]. Available at: https://doi.org/10.2139/ssrn.3205035.

[24] Van Daalen, K.R., Tonne, C., Semenza, J.C., Rocklöv, J., Markandya, A., Dasandi, N., Jankin, S., Achebak, H., Ballester, J., Bechara, H., Beck, T.M., Callaghan, M.W., Carvalho, B.M., Chambers, J., Pradas, M.C., Courtenay, O., Dasgupta, S., Eckelman, M.J., Farooq, Z., Fransson, P., Gallo, E., Gasparyan, O., Gonzalez-Reviriego, N., Hamilton, I., Hänninen, R., Hatfield, C., He, K., Kazmierczak, A., Kendrovski, V., Kennard, H., Kiesewetter, G., Kouznetsov, R., Kriit, H.K., Llabrés-Brustenga, A., Lloyd, S.J., Batista, M.L., Maia, C., Martinez-Urtaza, J., Mi, Z., Milà, C., Minx, J.C., Nieuwenhuijsen, M., Palamarchuk, J., Pantera, D.K., Quijal-Zamorano, M., Rafaj, P., Robinson, E.J.Z., Sánchez-Valdivia, N., Scamman, D., Schmoll, O., Sewe, M.O., Sherman, J.D., Singh, P., Sirotkina, E., Sjödin, H., Sofiev, M., Solaraju-Murali, B., Springmann, M., Treskova, M., Triñanes, J., Vanuytrecht, E., Wagner, F., Walawender, M., Warnecke, L., Zhang, R., Romanello, M., Antó, J.M., Nilsson, M. and Lowe, R. (2024) "The 2024 Europe report of the Lancet Countdown on health and climate change: unprecedented warming demands unprecedented action," ˜ the Lancet. Public Health, 9(7), pp. e495–e522. Available at: https://doi.org/10.1016/s2468-2667(24)00055-0.

[25] Venter, Z.S., Barton, D.N., Gundersen, V., Figari, H. and Nowell, M. (2020) "Urban nature in a time of crisis: recreational use of green space increases during the COVID-19 outbreak in Oslo, Norway," Environmental Research Letters, 15(10), p. 104075. Available at: https://doi.org/10.1088/1748-9326/abb396.

[26] Wang, R. (2023) "Enhancing energy efficiency with smart grid technology: a fusion of TCN, BiGRU, and attention mechanism," Frontiers in Energy Research, 11. Available at: https://doi.org/10.3389/fenrg.2023.1283026.

[27] Yang, P., Xiong, N. and Ren, J. (2020) "Data Security and Privacy Protection for Cloud Storage: A Survey," IEEE Access, 8, pp. 131723–131740. Available at: https://doi.org/10.1109/access.2020.3009876.

[28] Yau, K.-L.A., Peng, S., Qadir, J., Low, Y.-C. and Ling, M.H. (2020) "Towards Smart Port Infrastructures: Enhancing Port Activities Using Information and Communications Technology," IEEE Access, 8, pp. 83387–83404. Available at: https://doi.org/10.1109/access.2020.2990961.

[29] Yildiz, B., Bilbao, J.I., Dore, J. and Sproul, A.B. (2017) "Recent advances in the analysis of residential electricity consumption and applications of smart meter data," Applied Energy, 208, pp. 402–427. Available at: https://doi.org/10.1016/j.apenergy.2017.10.014.

[30] Yu, X. and Xue, Y. (2016) "Smart Grids: A Cyber-Physical Systems Perspective," Proceedings of the IEEE, 104(5), pp. 1058–1070. Available at: https://doi.org/10.1109/jproc.2015.2503119.

[31] Zhang, L., Nan, Z., Xu, Y. and Li, S. (2016) "Hydrological Impacts of Land Use Change and Climate Variability in the Headwater Region of the Heihe River Basin, Northwest China," PloS One, 11(6), p. e0158394. Available at: https://doi.org/10.1371/journal.pone.0158394.