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Climate Change and Small Businesses Leveraging AI for Adaptation and Resilience

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ABSTRACT

Climate change has emerged as a major global challenge, significantly impacting small-scale businesses and startups, particularly in sectors such as agriculture, manufacturing, energy, and retail. These businesses often lack the financial and infrastructural resilience to cope with climate-induced disruptions, making them highly vulnerable to extreme weather events, fluctuating resource availability, and changing consumer behaviors. However, the integration of Machine Learning (ML) and Deep Learning (DL) algorithms presents new opportunities to mitigate risks and enhance adaptive strategies. This paper provides a comprehensive review of how ML and DL models, including Random Forest, Support Vector Machines (SVM), Artificial Neural Networks (ANNs), Long Short-Term Memory (LSTM), and Convolutional Neural Networks (CNNs), are being used to forecast climate-induced risks, optimize supply chains, reduce operational inefficiencies, and ensure business continuity. Additionally, real-world case studies demonstrate how AI-driven climate adaptation strategies have helped businesses improve decision-making and sustainability.

Keywords: Climate Change; Small-Scale Businesses; Startups; Machine Learning; Deep Learning; Climate Resilience; AI-driven Sustainability; Business Risk Mitigation; Artificial Intelligence; Supply Chain Optimization; Sustainability; Business Continuity; Climate Risk Management.

1. Introduction

Climate change is no longer a distant threat but an ongoing crisis affecting economies and societies worldwide. The increasing frequency of extreme weather events such as hurricanes, floods, droughts, and heat waves has severe implications for businesses, particularly small-scale enterprises and startups that lack the resources and infrastructure to cope with these disruptions. Unlike large corporations, which have substantial financial buffers and access to advanced technologies, small businesses struggle to recover from climate-related disasters, making them highly susceptible to economic instability.

According to the Intergovernmental Panel on Climate Change (IPCC, 2023), global temperatures have risen significantly over the past few decades, leading to an increase in climate-induced risks. These risks include supply chain disruptions, increased energy consumption, regulatory compliance challenges, and shifting consumer demand. Given these threats, small-scale businesses need adaptive strategies to ensure their survival and long-term sustainability.

Artificial Intelligence (AI), particularly Machine Learning (ML) and Deep Learning (DL), offers promising solutions for climate risk management. AI-powered predictive models can analyze historical climate data, assess risk factors, and provide actionable insights to help businesses mitigate climate-related threats. By leveraging AI-driven strategies, small businesses can make data-informed decisions to optimize their supply chains, reduce operational costs, and develop sustainable business models. This paper explores how ML and DL technologies can be effectively integrated into small business operations to enhance climate resilience, offering insights into real-world applications, challenges, and future research directions.

1.1. Study Objectives

1) To investigate how climate change affects the operational efficacy and sustainability of small businesses and startups.

2) To pinpoint the primary climate-related threats that impact small enterprises, such as disruptions in the supply chain, increased operational expenses, regulatory hurdles, and shifts in consumer preferences.

3) To assess how Machine Learning (ML) techniques can aid in forecasting climate risks and facilitating business continuity planning.

4) To examine the efficiency of Deep Learning (DL) applications in climate observation, resource optimization, and environmental risk management for small businesses.

5) To investigate AI-based strategies that improve climate resilience, operational effectiveness, and sustainable practices among small enterprises.

6) To present a framework and recommendations for the incorporation of AI technologies to enhance climate adaptation and long-term resilience in small businesses and startups.

2. Impact Of Climate Change on Small-Scale Businesses

Climate change affects small businesses in multiple ways, ranging from disruptions in supply chains to increased operational expenses. One of the most significant challenges is the unpredictability of extreme weather events, which can halt business operations, delay logistics, and lead to substantial financial losses. In sectors such as agriculture and retail, where seasonal changes significantly impact production and sales, climate variability poses an even greater risk.

Supply chain disruptions are one of the most critical consequences of climate change for small businesses. Extreme weather conditions, such as hurricanes and floods, can cause transportation delays, disrupt manufacturing processes, and create shortages of raw materials. For example, agricultural startups dependent on climate-sensitive crops face significant risks due to unpredictable weather patterns. Machine learning models such as Random Forest and Gradient Boosting can be used to analyze climate trends and predict supply chain disruptions, enabling businesses to take proactive measures to mitigate risks.

Another major impact of climate change is the rising cost of operations. Higher temperatures increase energy consumption, particularly for businesses that rely on refrigeration, air conditioning, and other climate-sensitive infrastructure. AI-driven energy optimization models, such as those utilizing Deep Reinforcement Learning, have shown great promise in reducing energy consumption while maintaining operational efficiency. Additionally, evolving

environmental regulations require businesses to comply with stricter carbon emission standards, adding financial pressure to small enterprises. AI-powered Natural Language Processing (NLP) tools can help businesses stay updated with regulatory changes and ensure compliance with environmental laws.

Shifting consumer demand is another challenge that businesses must navigate in the wake of climate change. As awareness of climate-related issues grows, consumers increasingly prefer sustainable products and services. Businesses must adapt their offerings accordingly, and AI-driven sentiment analysis models can help by analyzing

market trends and predicting consumer behavior. For example, demand forecasting using LSTM models enables retailers to anticipate seasonal variations in sales, allowing them to adjust inventory and pricing strategies accordingly.

Diaz Tautiva, J. A., Barros, S., Lecuna, A., & Barragan-Rodriguez, C. (2025) conducted a bibliometric and systematic literature review on climate change strategies in SMEs. The study analyzed 91research articles and found that climate adaptation research for SMEs has expanded rapidly since 2020. The authors emphasized the importance of digital technologies, including AI, for improving business resilience, while identifying significant research gaps in developing countries.

Ho, S. Y., & Iyke, B. N. (2026) reviewed climate resilience in small enterprises by synthesizing evidence from 89 studies. The research found that SMEs face financial limitations, information gaps, and institutional barriers in responding to climate change. The authors suggested digital technologies, including AI, as effective tools for risk assessment, early warning, and adaptive planning

2.1. Supply Chain Disruptions

Unpredictable climate events such as floods, droughts, hurricanes, and extreme temperatures disrupt supply chains, causing delays in raw material procurement, transportation, and inventory management. ML-based predictive analytics can forecast weather-related disruptions, allowing businesses to proactively adjust their logistics and storage plans (Fahimnia et al., 2021).

2.2. Increased Operational Costs

Grover, A., & Kahn, M. E. (2025/2026) reviewed firm-level climate adaptation strategies, focusing on businesses in developing economies. Their findings indicate that climate resilience depends on investment in technology, infrastructure, and organizational capabilities. The study recommends integrating AI-based decision-support systems into business operations to enhance adaptive capacity

Climate change directly affects energy consumption, insurance premiums, and resource availability. For instance, a rise in temperature increases cooling and refrigeration costs for small-scale food businesses. AI-powered energy optimization models using Reinforcement Learning (RL) can dynamically adjust energy usage, reducing costs without compromising efficiency (Chen et al., 2022).

2.3. Consumer Demand Variability

Changing climate patterns influence consumer behavior, affecting seasonal demand for products and services. AI-driven demand forecasting models, such as ARIMA and LSTM networks, analyze historical climate and sales data to predict market trends, allowing businesses to adjust production and marketing strategies accordingly (Sharma & Singh, 2023).

2.4. Compliance with Environmental Regulations

Governments worldwide are introducing strict carbon emission regulations and sustainability policies. Small businesses must adapt their operations to comply with these regulations, often with limited resources. AI-powered

Natural Language Processing (NLP) systems can analyze legal frameworks and provide businesses with customized compliance recommendations (Kumar & Roy, 2021).

3. Machine Learning Applications in Climate Risk Management

Machine Learning has proven to be an effective tool in climate risk management by enabling businesses to predict, assess, and respond to climate-related threats. One of the key areas where ML is making a difference is predictive climate risk forecasting. Algorithms such as LSTM and ARIMA analyze historical weather data to identify patterns and predict future climate events. These models allow businesses to develop contingency plans and take proactive measures to protect their assets.

Decision support systems powered by ML play a crucial role in business continuity planning. Support Vector Machines (SVM) and Bayesian Networks can categorize businesses based on their exposure to climate risks, helping them allocate resources more efficiently. Additionally, ML-powered supply chain optimization models analyze weather patterns and adjust logistics operations to minimize disruptions.

One of the most impactful applications of ML is AI-driven demand forecasting. Climate variability affects consumer behavior, making it essential for businesses to adapt to changing market conditions. ML algorithms can process large datasets to determine how climate factors influence consumer preferences, enabling businesses to make informed decisions about inventory management, pricing, and marketing strategies.

3.1. Predictive Climate Risk Forecasting

Moisello, A. M. (2026) reviewed climate resilience in family firms and found that governance structures, organizational identity, and adaptive capabilities are essential for long-term resilience. The study recommended adopting digital technologies, including AI-based analytical tools, to improve decision-making under climate uncertainty.

Machine Learning models can analyze historical climate data and predict future risk probabilities.

- Random Forest & XG Boost: Used for classifying businesses based on their climate risk exposure.
- LSTM (Long Short-Term Memory): Predicts seasonal demand and climate-related disruptions.

Real-World Example:

➢ Agritech startups use ML to forecast droughts and optimize irrigation systems, reducing water consumption by 20%.

3.2. Decision Support Systems for Business Adaptation

AI-driven Decision Support Systems (DSS) integrate climate, financial, and market data to assist businesses in making informed strategic decisions (Chen et al., 2022).

- Support Vector Machines (SVM): Helps businesses classify high-risk and low-risk investment areas based on climate exposure.
- Bayesian Networks: Used for scenario analysis and risk assessment.

Real-World Example:

➢ Renewable energy startups use Bayesian Networks to analyze solar energy potential based on climate trends, optimizing solar panel installations.

4. Deep Learning for Climate Adaptation in Small Businesses

Costa, M., Vandervoort, A., Schmidt, C., et al. (2026) proposed a reinforcement learning framework for climate adaptation planning. Although focused on transport infrastructure, the study demonstrates how AI-driven predictive models can optimize long-term adaptation strategies, providing useful insights for SMEs seeking to strengthen resilience against climate risks

Villano, D., Colli, L., Martellozzo, F., & Lombardi, S. (2026) conducted a systematic literature review on business climate adaptation and resilience. The study concluded that resilience depends on organizational learning, technological innovation, and stakeholder collaboration. It also highlighted AI as an emerging technology supporting climate adaptation and sustainable business practice

Deep Learning has revolutionized climate adaptation strategies by providing advanced capabilities in environmental monitoring, automated decision-making, and climate risk assessment. Convolutional Neural Networks (CNNs) are widely used in environmental monitoring to analyze satellite images, detect changes in land use, and monitor deforestation. Businesses in the agriculture and energy sectors use CNN-based models to track climate patterns and assess their impact on production.

Another critical application of DL is reinforcement learning for smart resource allocation. Reinforcement learning models optimize resource usage in industries such as manufacturing and logistics by dynamically adjusting supply chain operations in response to climate variability. Additionally, NLP-based AI tools help businesses analyze climate policies and ensure compliance with environmental regulations.

4.1. Convolutional Neural Networks (CNNs) for Climate Monitoring

CNNs analyze satellite images, drone footage, and IoT sensor data to track climate changes affecting businesses (Li et al., 2023).

- Use Case: Farming startups utilize CNNs to monitor soil moisture levels, crop health, and deforestation impacts.

4.2. Reinforcement Learning for Smart Resource Allocation

Reinforcement Learning (RL) is used for automated decision-making in supply chain management.

- Use Case: Retail chains use RL to dynamically adjust inventory levels and warehouse stocking based on predicted climate events.

4.3. Deep Learning Applications in Business Adaptation

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4.4. Real-World Case Studies

Several industries have successfully implemented AI-driven climate adaptation strategies. Agricultural startups are using AI-powered drought prediction models to optimize irrigation and prevent crop failures. In retail and supply chain management, ML algorithms are improving demand forecasting and reducing inventory waste. The energy sector has also benefited from AI-driven smart grids, which optimize energy distribution based on real-time climate data.

5. Challenges and Future Research Directions

While AI technologies offer tremendous potential, small businesses face certain barriers in adopting ML/DL solutions.

5.1. Data Availability and Accessibility

Climate datasets are often fragmented, unstructured, or expensive, making it difficult for small businesses to implement AI solutions.

5.2. High Computational Costs

Training and deploying complex DL models require advanced computing resources, which may not be affordable for startups.

5.3. Need for Explainable AI (XAI)

Ayadi, R., Forouheshfar, Y., & Moghadas, O. (2025) presented a systematic review of 385 studies examining AI applications for climate resilience. The review concluded that AI is increasingly used in climate adaptation through predictive analytics, risk forecasting, and decision support. However, the authors noted that AI adoption among small businesses remains limited due to financial and technical constraints.

Businesses need transparent, interpretable AI models that provide clear insights rather than complex black-box predictions.

Future Research Directions:

1. Developing low-cost AI solutions tailored for small businesses.
2. Expanding AI-driven climate financial risk models.
3. Exploring Hybrid AI models combining ML, DL, and blockchain for sustainable business practices.

6. Future Suggestions

The following recommendations for the future are suggested in light of the study's findings:

a) **Create reasonably priced AI solutions** especially for small companies with limited funding and technology.

b) **Encourage government support** for the use of AI for climate resilience through financial aid, tax breaks, and subsidies.

c) **Create unified climate data platforms** that offer small businesses dependable, up-to-date, and easily accessible climate information.

d) **To increase managerial confidence**, trust, and transparency, incorporate Explainable Artificial Intelligence (XAI) into commercial decision-making systems.

e) **Boost AI capacity building** by offering entrepreneurs and small company owners training and digital skill development programs.

f) **Promote public private collaborations** to help SMEs with climate adaption, AI innovation, and technology transfer.

g) **Create hybrid intelligent systems** to enhance business resilience and climate forecasting by combining machine learning, deep learning, the Internet of Things (IoT), geographic information systems (GIS), and blockchain.

h) **Increase industry-specific AI applications** for especially climate-vulnerable industries like agriculture, retail, manufacturing, logistics, tourism, and energy.

i) **To assess the long-term efficacy of AI-based climate adaption techniques** across various industries and geographical areas, conduct empirical and longitudinal research.

j) **To support resilient and ecologically sustainable business ec**osystems, align AI deployment with national climate policy and the Sustainable Development Goals (SDGs) of the United Nations.

7. Conclusion

Machine Learning and Deep Learning have emerged as transformative technologies for climate adaptation in small businesses and startups. By leveraging AI-driven predictive models, businesses can improve risk assessment, optimize supply chains, and enhance sustainability efforts. However, further research and innovation are required to ensure that AI solutions are accessible, interpretable, and cost-effective for small businesses.

Declarations

Source of Funding

This study has not received any funds from any organization.

Conflict of Interest

The authors declare that they have no conflict of interest.

Consent for Publication

The authors declare that they consented to the publication of this study.

Authors' Contribution

Both the authors took part in literature review, analysis, and manuscript writing equally.

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