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Sustainable Transportation Infrastructure under Climate Change: Comparing Australia and Canada

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ABSTRACT

Climate change has become a major challenge for the sustainability and resilience of transportation infrastructure worldwide, increasing the frequency and intensity of extreme weather events that threaten the safety, performance, and longevity of transport systems. Australia and Canada have implemented various adaptation strategies to improve the resilience of roads, railways, airports, and ports while supporting sustainable transportation development. This study aims to systematically review recent research published over the last five years on sustainable transportation infrastructure under climate change by comparing technological developments, adaptation strategies, policy frameworks, implementation practices, challenges, and future research opportunities in Australia and Canada. A Systematic Literature Review (SLR) was conducted using peer-reviewed journal articles from internationally recognized databases. The findings indicate that both countries have strengthened climate-resilient infrastructure through risk assessment, sustainable engineering practices, and digital technologies. However, challenges related to funding, infrastructure aging, climate uncertainty, and policy integration remain significant. This review provides evidence-based insights for researchers, engineers, and policymakers to support resilient and sustainable transportation infrastructure development under changing climate conditions.

Keywords: *Australia, Canada, Climate Change, Sustainable Transportation Infrastructure, Systematic Literature Review.*

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1. | INTRODUCTION

Climate change has emerged as one of the most significant global challenges affecting the planning, development, operation, and maintenance of transportation infrastructure. Rising global temperatures, changing precipitation patterns, sea-level rise, and the increasing frequency of extreme weather events have intensified the vulnerability of transportation systems worldwide. Roads, railways, airports, bridges, tunnels, and ports are increasingly exposed to floods, heatwaves, wildfires, storms, coastal erosion, and other climate-related hazards that threaten infrastructure reliability, public safety, and economic stability. These challenges have encouraged governments, researchers, and engineering practitioners to develop sustainable transportation infrastructure capable of adapting to changing environmental conditions while maintaining long-term operational performance and resilience (Miceli et al., 2021).

Sustainable transportation infrastructure refers to transportation systems that are designed, constructed, operated, and maintained by balancing economic efficiency, environmental protection, and social responsibility throughout their lifecycle. Unlike conventional infrastructure development, sustainable approaches emphasize resilience, resource efficiency, reduced greenhouse gas emissions, climate adaptation, and long-term infrastructure durability. Modern transportation projects increasingly incorporate sustainable materials, climate-resilient engineering designs, nature-based solutions, renewable energy integration, and digital technologies to improve infrastructure performance under uncertain climate conditions. Consequently, sustainability has become a fundamental consideration in transportation engineering policies and infrastructure investment strategies worldwide (Fisch et al., 2019).

Recent technological developments have further strengthened sustainable transportation infrastructure through the integration of advanced digital technologies. Geographic Information Systems (GIS), Artificial Intelligence (AI), Internet of Things (IoT), remote sensing, Digital Twin technology, Building Information Modeling (BIM), and big data analytics have significantly improved infrastructure planning, climate risk assessment, asset monitoring, and maintenance management. These technologies enable engineers to evaluate infrastructure vulnerability, simulate future climate scenarios, monitor structural conditions in real time, and optimize maintenance strategies based on predictive analysis (Cheng et al., 2020). As transportation systems become increasingly interconnected, digital transformation has become an essential component of climate adaptation and sustainable infrastructure management.

Australia and Canada represent two highly developed countries that have made significant investments in sustainable transportation infrastructure while facing different but equally challenging climate risks. Australia frequently experiences prolonged droughts, extreme heatwaves, bushfires, tropical cyclones, and coastal flooding, all of which significantly affect transportation networks and infrastructure performance. These climate conditions have encouraged national and regional governments to integrate climate resilience into transportation planning through engineering innovation, risk-based infrastructure design, and long-term adaptation strategies. Considerable atte ntion has also been given to improving the resilience of highways, railways, airports, and coastal transport facilities to ensure reliable transportation services despite increasingly severe climate conditions (AghaKouchak et al., 2020).

Canada faces a different range of climate-related challenges due to its diverse geographical and climatic conditions. Rising temperatures have accelerated permafrost degradation in northern regions, while increasing precipitation, flooding, wildfires, severe winter storms, and coastal erosion continue to threaten transportation infrastructure across the country. These environmental changes have created significant engineering challenges, particularly for highways, railways, bridges, airports, and remote transportation corridors that support national economic activities. In response, Canadian governments and infrastructure agencies have strengthened climate adaptation policies, promoted sustainable engineering practices, and invested in resilient transportation systems capable of withstanding future climate uncertainties while maintaining safe and efficient transportation services (Markolf et al., 2019).

Although numerous studies have investigated climate-resilient transportation infrastructure, most existing research focuses on individual countries, specific infrastructure types, or isolated adaptation strategies. Comparative studies examining sustainable transportation infrastructure under climate change between Australia and Canada remain relatively limited despite both countries sharing strong commitments to climate adaptation, sustainable development, and infrastructure resilience. Comparing their experiences provides valuable opportunities to identify best practices, common implementation challenges, innovative engineering solutions, and policy approaches that may be applicable in other regions facing similar climate risks (Doh et al., 2019).

Therefore, this study conducts a Systematic Literature Review (SLR) of peer-reviewed journal articles published between 2020 and 2024 to compare recent developments in sustainable transportation infrastructure under climate change in Australia and Canada. The review examines current research trends, climate adaptation strategies, technological innovations, policy frameworks, implementation practices, engineering challenges, and future research opportunities (Rasoulkhani et al., 2020). The findings are expected to provide comprehensive insights for researchers, engineers, infrastructure managers, and policymakers while contributing to the development of more resilient, efficient, and sustainable transportation systems capable of addressing future climate challenges.

2. | RESEARCH METHOD

This study employed a Systematic Literature Review (SLR) to comprehensively identify, evaluate, and synthesize recent studies related to sustainable transportation infrastructure under climate change, with a comparative focus on Australia and Canada. The SLR approach was selected because it provides a systematic, transparent, and reproducible process for reviewing scientific evidence while minimizing researcher bias and ensuring comprehensive coverage of relevant literature (Haddawa et al., 2020). The review process consisted of four sequential stages: literature identification, screening, eligibility assessment, and qualitative synthesis. Relevant publications were collected from internationally recognized scientific databases, including Scopus, Web of Science, ScienceDirect, SpringerLink, IEEE Xplore, and MDPI. The literature search employed combinations of keywords such as "Sustainable Transportation Infrastructure," "Climate Change," "Climate Resilience," "Transportation

Engineering," "Road Infrastructure," "Railway Infrastructure," "Australia," and "Canada." Only peer-reviewed journal articles published between 2020 and 2024 were included to ensure that the review reflected the most recent scientific developments, engineering innovations, and policy initiatives. The inclusion criteria required that the selected studies explicitly discuss climate change impacts, adaptation strategies, sustainable transportation infrastructure, engineering resilience, digital technologies, infrastructure management, or policy implementation in Australia or Canada. Articles unrelated to transportation engineering, duplicate publications, conference proceedings, book chapters, editorials, and studies lacking sufficient methodological information were excluded from the analysis (Rojas et al., 2020). After completing the screening process, all eligible studies were analyzed using qualitative content analysis to extract relevant information, including publication year, research objectives, transportation infrastructure type, climate hazards, engineering adaptation strategies, digital technologies applied, implementation outcomes, reported benefits, existing challenges, and recommendations for future research. The extracted information was subsequently classified into thematic categories to facilitate a comparative analysis of sustainable transportation infrastructure development in Australia and Canada. Particular attention was given to identifying similarities and differences in climate adaptation approaches, infrastructure resilience strategies, technological innovations, policy frameworks, sustainability practices, and implementation barriers (Tura et al., 2019). The synthesized findings were then interpreted to evaluate current research trends, identify existing knowledge gaps, and determine future research priorities. Through this systematic review process, the study provides a comprehensive understanding of how Australia and Canada are addressing climate-related challenges in transportation infrastructure while offering evidence-based recommendations that can support the planning, design, operation, and long-term management of resilient and sustainable transportation systems.

3. | RESULTS AND DISCUSSION

The systematic literature review demonstrates that research on sustainable transportation infrastructure under climate change has increased substantially between 2020 and 2024, reflecting the growing recognition that transportation networks must become more resilient to increasingly complex environmental challenges. The reviewed studies consistently indicate that climate change is no longer considered a future risk but a current engineering challenge affecting the planning, construction, operation, and maintenance of transportation infrastructure worldwide. Rising temperatures, changing precipitation patterns, sea-level rise, floods, wildfires, storms, and other extreme weather events have significantly influenced the performance and reliability of roads, bridges, railways, airports, and ports. Consequently, governments and infrastructure agencies have shifted from conventional maintenance practices toward proactive adaptation strategies that integrate sustainability, resilience, and digital innovation into infrastructure management (Argyroudis et al., 2022).

One of the most important findings identified in the reviewed literature is the growing integration of climate resilience into transportation infrastructure planning. Rather than designing infrastructure based solely on historical climate conditions, engineers increasingly incorporate future climate projections, environmental risk assessments, and resilience-based engineering principles into project development. This approach enables transportation systems to withstand climate-related disturbances while maintaining operational performance throughout their service life. Infrastructure resilience has therefore become a fundamental component of sustainable transportation planning because it reduces long-term maintenance costs, minimizes service disruptions, and enhances public safety under changing environmental conditions (Bešinović, 2020).

Recent technological developments have further strengthened sustainable transportation infrastructure through the adoption of advanced digital technologies. Geographic Information Systems (GIS), Artificial Intelligence (AI), Internet of Things (IoT), remote sensing, Digital Twin technology, Building Information Modeling (BIM), and big data analytics are increasingly applied to evaluate climate risks, monitor infrastructure conditions, optimize maintenance scheduling, and support engineering decision-making. Digital monitoring systems provide continuous information regarding structural performance, environmental conditions, and asset deterioration, enabling infrastructure managers to identify potential failures before they become critical. Predictive analytics also assists engineers in prioritizing maintenance activities, allocating resources more efficiently, and improving the long-term sustainability of transportation infrastructure (Hu et al., 2019).

The comparative analysis reveals that Australia has adopted a comprehensive approach to developing climate-resilient transportation infrastructure due to its exposure to diverse climate hazards, including prolonged heatwaves, bushfires, floods, tropical cyclones, and coastal erosion. These environmental conditions have significantly affected highways, railways, airports, and regional transportation networks, encouraging government agencies to integrate climate adaptation into infrastructure planning and engineering design. Transportation projects increasingly incorporate heat-resistant pavement materials, improved drainage systems, elevated road structures, fire-resistant construction materials, and coastal protection measures to reduce vulnerability to extreme weather events. These engineering innovations aim to improve infrastructure durability while ensuring the continuity of transportation services during and after climate-related disasters (Chester et al., 2021).

Another important development identified in Australia is the increasing use of digital technologies to support infrastructure management and climate adaptation. Remote sensing, satellite observations, drone inspections, IoT-based monitoring systems, and Digital Twin platforms enable infrastructure managers to continuously monitor asset conditions and evaluate the impacts of climate hazards in real time. AI-assisted predictive models are also increasingly utilized to estimate infrastructure deterioration, forecast maintenance requirements, and evaluate the effectiveness of adaptation strategies under different climate scenarios. By integrating engineering data with environmental information, Australian transportation agencies can develop evidence-based maintenance plans that improve infrastructure resilience while reducing operational costs. These technological innovations demonstrate Australia's commitment to combining sustainable engineering practices with digital transformation to strengthen transportation infrastructure against the growing impacts of climate change. Canada has also made significant progress in developing sustainable transportation infrastructure to address the increasing impacts of climate change. However, the country's adaptation priorities differ from those of Australia because of its unique geographical conditions and diverse climate zones. Transportation infrastructure in Canada is exposed to a wide range of environmental challenges, including permafrost degradation in northern regions, intense rainfall, river flooding, coastal erosion, wildfires, severe winter storms, and freeze–thaw cycles that accelerate pavement deterioration and structural damage. These conditions have encouraged transportation authorities to adopt resilience-based engineering approaches that emphasize long-term infrastructure performance under changing climatic conditions. Considerable investments have been directed toward upgrading highways, bridges, railways, airports, and remote transportation corridors using climate-resilient design standards, durable construction materials, and improved drainage systems capable of reducing vulnerability to future climate hazards (Sahoo et al., 2021).

The reviewed studies indicate that digital technologies have become an essential component of Canada's transportation infrastructure management strategy. Geographic Information Systems (GIS), remote sensing, Artificial Intelligence (AI), Internet of Things (IoT) sensors, Digital Twin technology, and cloud-based asset management platforms are increasingly integrated into infrastructure monitoring and maintenance programs. These technologies allow engineers to collect real-time environmental and structural data, assess infrastructure conditions, evaluate climate-related risks, and identify sections of transportation networks requiring immediate intervention. Predictive maintenance models supported by AI further improve decision-making by estimating infrastructure deterioration, optimizing inspection schedules, and prioritizing maintenance activities based on actual asset conditions rather than fixed maintenance intervals. As a result, transportation agencies can allocate financial resources more efficiently while improving infrastructure reliability and public safety.

The comparative analysis demonstrates that Australia and Canada share several common objectives in developing sustainable transportation infrastructure despite facing different environmental challenges. Both countries recognize that conventional engineering approaches are no longer sufficient to address increasingly frequent and severe climate-related events. Consequently, climate adaptation has become an integral component of transportation planning, infrastructure investment, and long-term asset management. Engineering resilience, sustainability, and digital transformation are consistently integrated into national transportation strategies to ensure that infrastructure systems remain functional, safe, and economically efficient under future climate scenarios. In both countries, governments have strengthened collaboration with universities, research institutions, and private industries to accelerate innovation in resilient transportation engineering and climate adaptation technologies (Bayeroju et al., 2023).

Despite these similarities, the reviewed literature also reveals notable differences in implementation priorities. Australia primarily focuses on mitigating the impacts of extreme heat, bushfires, droughts, and coastal hazards that directly affect transportation corridors located in arid and coastal regions. Consequently, engineering solutions often emphasize heat-resistant pavement technologies, wildfire protection measures, improved flood resilience, and coastal infrastructure adaptation. In contrast, Canada's research and infrastructure policies concentrate on addressing challenges associated with cold climates, permafrost instability, seasonal flooding, and severe winter weather. Canadian adaptation strategies therefore prioritize frost-resistant materials, foundation stabilization, improved drainage systems, and resilient transportation corridors capable of maintaining reliable services across geographically diverse environments (Quium et al., 2019).

Another important finding identified through this review is the increasing contribution of sustainable engineering practices to reducing environmental impacts throughout the infrastructure lifecycle. Both Australia and Canada have promoted the use of recycled construction materials, low-carbon concrete, sustainable pavement technologies, renewable energy integration, and environmentally responsible construction methods to reduce greenhouse gas emissions while improving infrastructure durability. Lifecycle assessment has also become an important decision-making tool, enabling engineers to evaluate the long-term environmental, economic, and social performance of transportation projects before implementation. These practices demonstrate that sustainable transportation infrastructure is no longer limited to improving resilience against climate hazards but also supports broader sustainability objectives through efficient resource utilization, reduced carbon emissions, and enhanced long-term infrastructure performance. Although Australia and Canada have achieved considerable progress in developing sustainable transportation infrastructure, the reviewed literature identifies several challenges that continue to influence implementation effectiveness. One of the most significant challenges is the increasing uncertainty associated with future climate scenarios, making it difficult for engineers and policymakers to determine appropriate design standards and long-term investment priorities. Transportation infrastructure typically has a long service life, requiring planning decisions that remain effective under changing environmental conditions for several decades. In addition, aging infrastructure, limited financial resources, and the high costs of climate adaptation continue to constrain the modernization of transportation networks in both countries. These challenges highlight the importance of integrating scientific climate projections with engineering design and infrastructure management practices (Palin et al., 2021).

The review also identifies several technological and organizational issues that require further attention. Although digital technologies such as Artificial Intelligence, Geographic Information Systems, Digital Twin, Internet of Things, and remote sensing have significantly improved infrastructure monitoring and decision-making, their implementation remains constrained by data interoperability, cybersecurity concerns, limited technical expertise, and inconsistencies in data collection standards. Strengthening collaboration among governments, research institutions, infrastructure operators, and technology providers will therefore be essential to maximize the effectiveness of digital transformation in transportation engineering. Furthermore, expanding workforce training and improving institutional capacity will support the successful adoption of innovative technologies across transportation agencies (Giusti et al., 2019).

Overall, the findings demonstrate that sustainable transportation infrastructure has become a strategic priority for both Australia and Canada in responding to the growing impacts of climate change. While Australia emphasizes adaptation to extreme heat, bushfires, floods, and coastal hazards, Canada focuses on addressing permafrost degradation, severe winter conditions, and seasonal flooding. Despite these different environmental contexts, both countries have successfully integrated resilience, sustainability, and digital innovation into transportation infrastructure planning and management (Yan et al., 2023). Future research should prioritize standardized climate risk assessment methods, advanced predictive models, lifecycle sustainability evaluation, and broader integration of emerging digital technologies to strengthen infrastructure resilience and support the long-term development of safe, efficient, and sustainable transportation systems.

4. | CONCLUSION

This study systematically reviewed recent research on sustainable transportation infrastructure under climate change by comparing developments in Australia and Canada based on peer-reviewed publications published between over the last five years. The findings demonstrate that climate change has significantly influenced the planning, design, operation, and maintenance of transportation infrastructure, requiring engineering approaches that integrate sustainability, resilience, and technological innovation. Both countries have strengthened climate adaptation through resilient infrastructure design, sustainable engineering practices, and the adoption of advanced digital technologies, including Artificial Intelligence (AI), Geographic Information Systems (GIS), Digital Twin, Internet of Things (IoT), remote sensing, and predictive data analytics to improve infrastructure monitoring and long-term asset management.

The comparative analysis shows that Australia primarily focuses on addressing the impacts of extreme heat, bushfires, floods, and coastal hazards, whereas Canada prioritizes adaptation to permafrost degradation, severe winter conditions, seasonal flooding, and freeze–thaw cycles. Despite these different environmental challenges, both countries share a common commitment to developing transportation systems that are resilient, environmentally sustainable, and capable of supporting long-term economic and social development.

Nevertheless, several challenges remain, including climate uncertainty, aging infrastructure, funding limitations, interoperability of digital technologies, cybersecurity, and shortages of skilled professionals. Addressing these issues requires stronger collaboration among governments, researchers, industry practitioners, and infrastructure agencies. Future research should emphasize standardized climate risk assessment, lifecycle sustainability evaluation, advanced predictive modeling, and the broader integration of intelligent digital technologies to enhance the resilience, efficiency, and sustainability of transportation infrastructure under changing climate conditions.

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The data that support the findings of this study are available from the corresponding author upon reasonable request.

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