Decarbonizing Australia's Rolling Stock: Insights for the Canadian Railway Sector

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Abstract

The railway sector plays a pivotal role in achieving national and global decarbonization targets due to its potential for high efficiency and reduced greenhouse gas (GHG) emissions compared to other modes of transportation. Australia has recently embarked on an ambitious journey to decarbonize its rolling stock, implementing innovative technologies, policy instruments, and strategic investments aimed at reducing the carbon footprint of both freight and passenger trains. This paper explores Australia's decarbonization initiatives in the rail sector and identifies key lessons that could be adapted for the Canadian context.

Drawing on a review of national and subnational policy documents, technical reports, and case studies, the paper presents a comprehensive overview of Australia's approaches, including the adoption of electric and hydrogen-powered trains, investments in renewable energy infrastructure, and the role of government-industry partnerships. The analysis highlights both achievements and barriers faced by Australian stakeholders in implementing low-carbon rail systems.

The Canadian railway sector, with its vast geography and significant reliance on diesel-powered locomotives, faces distinct challenges in its decarbonization path. However, by examining the Australian experience, valuable insights can be gained regarding policy alignment, technological readiness, financing models, and stakeholder engagement.

The findings suggest that Canada could accelerate its transition toward sustainable rail transport by adopting a multi-pronged strategy that incorporates lessons from Australia. These include the importance of long-term policy commitment, pilot projects for emerging technologies, regional adaptation of solutions, and public-private collaboration.

This paper contributes to the growing literature on sustainable transport by providing a cross-national perspective on rail decarbonization and offers practical recommendations for policymakers, industry leaders, and researchers in Canada aiming to build a greener, more resilient transportation future.

1.   Introduction

Climate change poses one of the most significant global challenges of the 21st century. With mounting evidence linking anthropogenic greenhouse gas (GHG) emissions to global warming and environmental degradation, governments and industries around the world are intensifying efforts to transition toward low-carbon economies. The transportation sector, which contributes approximately 24% of direct CO_2 emissions from fuel combustion globally, remains a key area of focus for decarbonization policies [1]. Within this sector, rail transport holds unique potential as a sustainable alternative to more carbon-intensive modes such as road and air travel. Rail systems, particularly when powered by clean electricity or alternative fuels, can provide efficient, large-scale, and low-emission mobility for both passengers and freight.

Australia, despite its historically limited investment in electrified rail compared to other developed nations, has recently launched several decarbonization initiatives aimed at transforming its rolling stock—locomotives and train carriages—into more environmentally sustainable assets. These efforts are driven by a combination of climate commitments, public demand for cleaner transportation, and the opportunity to modernize infrastructure in a way that aligns with future energy systems [2]. Recent projects include the deployment of electric and hydrogen-powered trains, the integration of renewable energy sources into rail networks, and a strategic push by both public and private stakeholders to reduce diesel reliance in long-haul freight operations [3].

The Canadian railway sector, with its vast network spanning over 50,000 kilometers and its significant dependence on diesel-powered locomotives, presents both opportunities and challenges in the quest for decarbonization. Freight transportation dominates rail usage in Canada, accounting for a substantial portion of GHG emissions from the sector [4]. However, Canada's extensive natural resources, technological capabilities, and policy momentum toward net-zero targets provide a fertile ground for adopting innovative solutions. By examining Australia's emerging experience in decarbonizing its rolling

stock, Canadian policymakers and industry leaders can gain actionable insights into the practical steps, barriers, and enablers involved in transitioning to low-carbon rail systems.

A central rationale for focusing on rolling stock lies in its long service life and embedded carbon footprint. Rolling stock assets often remain in operation for several decades, making early-stage decisions about their propulsion technologies and energy sources highly consequential in long-term emission trajectories [5]. Decarbonization efforts in this domain not only involve transitioning to cleaner fuels and propulsion systems but also require integrated approaches that address supply chains, energy infrastructure, and operational optimization. In Australia, state-level initiatives—such as New South Wales' target to achieve a zero-emission public transport system by 2050—demonstrate the growing ambition and experimentation with cleaner technologies [6].

Moreover, innovation in alternative propulsion technologies is rapidly evolving. Hydrogen fuel cells, battery-electric systems, and hybrid configurations are being tested and deployed across different regions of Australia, each with unique operating conditions and energy profiles. The Hydrail project in Queensland, for instance, exemplifies how rail systems can leverage local renewable energy resources for hydrogen production, thereby creating closed-loop, low-emission transit systems [7]. Similarly, Victoria's investment in bi-mode trains reflects a pragmatic approach to bridging existing diesel infrastructure with future electrification plans [8].

One of the key lessons emerging from the Australian experience is the importance of alignment between policy objectives and industrial capabilities. Collaborative frameworks that bring together government agencies, research institutions, and rolling stock manufacturers have proven critical in de-risking investments in emerging technologies and accelerating deployment timelines. For example, the partnership between Alstom and Transport for New South Wales has led to the introduction of electric trains equipped with regenerative braking systems, reducing overall energy consumption while enhancing operational efficiency [9].

From a Canadian perspective, the challenges of scale, geography, and climate demand tailored solutions. The vast distances covered by freight trains, the need for year-round resilience in cold environments, and the diversity of regional energy mixes necessitate flexible and context-sensitive strategies. While electrification remains a long-term goal, interim solutions such as renewable diesel and hydrogen blends may serve as transitional pathways toward deeper decarbonization [10]. Furthermore, Canada's growing interest in green hydrogen production, supported by federal and provincial investments, could enable synergies between the energy and transportation sectors, particularly in rail applications.

Another critical factor is the role of regulation and procurement in driving change. Australia's use of emission standards, procurement guidelines favoring low-carbon technologies, and investment in pilot programs has created an enabling environment for innovation. These policy levers could be adapted in Canada to incentivize private sector participation and stimulate domestic manufacturing of green rail technologies [11]. Additionally, lessons from Australia's stakeholder engagement practices—such as early consultation with communities and labor unions—highlight the need for inclusive and socially responsible transition planning.

The economic case for decarbonizing rail is also gaining traction. While the upfront costs of electrification or hydrogen propulsion systems may be high, lifecycle cost analyses increasingly show long-term savings through reduced fuel expenditures, lower maintenance costs, and environmental co-

benefits such as improved air quality and noise reduction [12]. Australia's cost-sharing models and public-private partnerships serve as useful precedents for Canadian decision-makers exploring funding mechanisms for low-carbon infrastructure.

In sum, the comparative study of decarbonization in Australia's rolling stock sector provides a timely opportunity for Canada to reflect on its own pathway to sustainable rail. The two countries, though different in size and population, share key characteristics such as vast territories, resource-based economies, and democratic governance systems, which make cross-national learning both relevant and valuable. By analyzing the technological, policy, and institutional dimensions of Australia's experience, this paper seeks to inform a more strategic and accelerated transition in the Canadian rail sector.

As climate urgency intensifies, the need for bold and coordinated action across sectors becomes increasingly apparent. Rail transport, as a backbone of national logistics and urban mobility, holds transformative potential if embedded within a broader vision of clean energy and sustainable infrastructure. The insights presented in this paper aim to contribute to that vision, offering a foundation for policy reform, investment strategies, and collaborative innovation tailored to the Canadian context.

2. Theoretical Framework and Literature Review

The decarbonization of the rail transport sector is situated within the broader theoretical framework of sustainable transportation and energy transition theory. These frameworks emphasize the necessity of shifting from fossil fuel-dependent systems toward low- or zero-emission alternatives through technological innovation, policy reform, and institutional transformation. Central to this perspective is the triple-bottom-line approach to sustainability—economic, environmental, and social performance— which guides strategic decisions in infrastructure and mobility planning [1].

From a systems perspective, rail transport is uniquely positioned within sustainable transport frameworks due to its potential for high energy efficiency, large-scale capacity, and low carbon intensity when electrified or powered by alternative fuels. Theoretical models such as the Avoid–Shift–Improve (ASI) framework further support the prioritization of rail over other transport modes by advocating for the reduction of unnecessary travel (avoid), modal shift toward efficient transport (shift), and improvement of technologies and fuels (improve) [2]. Under this lens, decarbonizing rolling stock is not only a technological endeavor but also a strategic reconfiguration of transport systems aligned with climate goals.

One of the earliest and most influential contributions to sustainable transport theory is Banister's model of sustainable mobility, which emphasizes the reduction of car dependency, investment in public transit, and integration of land use and transport planning [3]. This model has informed both academic and policy discourses on rail development, particularly in urban and suburban contexts. Moreover, recent literature in environmental economics has highlighted the co-benefits of rail decarbonization, including reductions in air pollution, noise, and operating costs—factors that strengthen the economic case for investment in clean rail technologies [4].

Turning to empirical research, a growing body of international studies has examined the technical and policy dimensions of rolling stock decarbonization. In Europe, where electrified rail networks are more widespread, scholars have focused on the comparative advantages of direct electrification versus

hydrogen and battery-electric solutions in different geographic and operational contexts. Research by Jäger et al. (2020) showed that while full electrification remains the most efficient solution for high-density corridors, hydrogen-powered trains offer a viable alternative in rural and low-traffic areas where catenary systems are cost-prohibitive [5].

In Australia, studies have primarily addressed the challenges of transitioning a historically diesel-reliant rail network into a modern, sustainable system. According to a report by the Australasian Railway Association (ARA, 2021), approximately 85% of Australia's freight rail services rely on diesel locomotives, making decarbonization a significant logistical and technological challenge [6]. However, pilot projects such as the deployment of hydrogen-powered trains in regional Queensland, and electric trains with renewable energy integration in Sydney and Melbourne, demonstrate a growing momentum for innovation and transition.

Ghosh et al. (2022) analyzed the policy mechanisms driving rail decarbonization in New South Wales, concluding that long-term procurement strategies, public-private partnerships, and the integration of renewable energy sources into grid infrastructure are key enabling factors [7]. Additionally, studies have explored the potential for using bi-mode and hybrid trains as transitional technologies that allow for partial electrification while infrastructure upgrades are phased in over time [8].

In the Canadian context, research on rail decarbonization remains comparatively limited but is expanding in light of national net-zero commitments. A recent study by Natural Resources Canada (2021) assessed the technical feasibility of hydrogen propulsion in the country's freight sector, concluding that while significant infrastructure investment would be required, the long-term benefits could justify the transition, particularly in corridors with access to green hydrogen production [9]. Similarly, the National Research Council of Canada has initiated projects exploring fuel cell integration, battery storage systems, and smart grid applications for rail operations [10].

Historical analysis of Canada's railway sector reveals a deep entrenchment in diesel technologies, stemming from its reliance on freight transport over vast and often remote territories. Studies by Hall and Weisbrod (2019) highlight that one of the main barriers to electrification is the cost and complexity of building overhead catenary systems across such extensive distances, which makes the case for alternative fuels stronger [11]. In this context, Australia's experimentation with decentralized hydrogen systems and regional electrification provides a valuable reference point.

The role of stakeholders—particularly government agencies, rail operators, manufacturers, and civil society—has also been the subject of increasing scholarly interest. A comparative analysis by Newton and Newman (2020) underscored the importance of collaborative governance models in achieving ambitious sustainability transitions, citing Australia's Smart Cities Plan and transport innovation zones as mechanisms that align infrastructure investment with decarbonization objectives [12]. In Canada, initiatives like the Canada Infrastructure Bank's funding for clean transportation projects suggest potential for similar alignment, though further coordination between federal, provincial, and municipal actors remains necessary.

Moreover, several studies have focused on the financial and institutional risks associated with technological lock-in and path dependency in the rail sector. According to Sovacool et al. (2021), decarbonization efforts must be carefully managed to avoid investing in transitional technologies that may become obsolete or uneconomical in the near future. This is especially relevant for large capital investments in rolling stock, where procurement decisions have long-lasting implications [13]. The

Australian experience, where multi-year tenders now prioritize emissions performance and energy efficiency, provides a model for how such risks can be mitigated through forward-looking procurement frameworks.

Finally, public perception and social acceptance have emerged as critical components in the successful implementation of rail decarbonization initiatives. Studies by Lee and Tranter (2022) reveal that public support for clean rail projects increases when these projects are framed in terms of health benefits, local job creation, and urban livability improvements, rather than solely as climate initiatives [14]. Australian states have increasingly adopted communication strategies that highlight such co-benefits, a practice that could enhance public buy-in for similar initiatives in Canada.

In summary, the theoretical and empirical literature underscores the multifaceted nature of rail decarbonization, encompassing technological innovation, regulatory frameworks, stakeholder engagement, and economic feasibility. While Australia and Canada differ in their rail infrastructures and policy landscapes, both countries share structural similarities—such as vast geographies, regional disparities, and resource-based economies—that make cross-learning especially valuable. By integrating the insights from existing research, this paper seeks to build a bridge between theoretical models and practical strategies for advancing rolling stock decarbonization in Canada.

3. Methodology

This study adopts a review-based research methodology, focusing on a comprehensive synthesis of existing literature, policy documents, technical reports, and case studies related to the decarbonization of rolling stock in Australia and its implications for the Canadian railway sector. The primary objective is to extract key patterns, lessons, and strategic insights that can inform policymaking, investment, and innovation in Canada's transport infrastructure.

A systematic literature review approach was employed to ensure the selection of high-quality, relevant, and up-to-date sources. The review included both academic peer-reviewed articles and grey literature such as government policy documents, white papers, industry reports, and feasibility studies published between 2015 and 2024. Key databases consulted for academic sources included Scopus, Web of Science, and Google Scholar, while institutional reports were sourced from organizations such as the Australasian Railway Association (ARA), Transport for New South Wales, Infrastructure Australia, Natural Resources Canada, and the National Research Council of Canada.

The search strategy involved the use of specific keywords and Boolean operators, including: "rail decarbonization", "rolling stock electrification", "hydrogen trains", "low-carbon transportation Australia", "rail innovation Canada", "green rail policies", and "sustainable rail transition". Selection criteria were based on the relevance to the topic, the credibility of the source, clarity of methodological framework (for empirical studies), and the contribution to understanding both the Australian and Canadian contexts.

After an initial pool of over 100 documents was collected, duplicates and non-relevant studies were excluded. The final dataset consisted of approximately 60 key documents, which were thematically analyzed. A qualitative content analysis method was used to extract and code information under the following categories:

(1) Policy frameworks and governmental strategies,

(2) Technological developments in rolling stock,
(3) Economic and environmental impacts,
(4) Institutional and stakeholder dynamics, and
(5) Barriers and enablers to implementation.

To ensure objectivity and mitigate potential bias in interpretation, cross-validation of findings was performed by comparing multiple sources discussing the same case or theme. Where appropriate, insights from secondary data were supported with statistical summaries provided in official government datasets or industry publications.

This review method allows for a nuanced, context-sensitive understanding of how decarbonization strategies have been conceptualized, operationalized, and evaluated in the Australian rail sector. It also facilitates the identification of transferrable best practices and potential pitfalls that may influence the design and execution of similar initiatives in Canada.

Given the exploratory and comparative nature of this study, no primary data collection (e.g., interviews, surveys, or field measurements) was conducted. However, future research could benefit from integrating stakeholder interviews and field case studies to validate the proposed insights and deepen the empirical grounding.

In sum, the methodological framework of this study is designed to bridge theoretical knowledge with practical experience, offering a robust foundation for recommendations tailored to Canada's unique infrastructural, environmental, and political landscape.

4. Results and Discussion

The decarbonization of rolling stock in Australia has progressed through a variety of technological, policy, and financial strategies that offer important insights for Canada. The review of implementation status, contextual relevance, and potential barriers reveals both transferable practices and the need for localized adaptation. This section presents an integrated analysis of six key strategies, with direct implications for the Canadian railway sector.

One of the most impactful approaches observed in Australia is the full electrification of rail corridors, particularly in urban centers such as Sydney and Melbourne. Projects like the Sydney Metro have demonstrated moderate but consistent reductions in operational emissions and increased service reliability. However, the cost of infrastructure installation, including catenary lines and substations, is significant. For Canada, where dense population centers exist in corridors such as the Quebec City-Windsor line, electrification presents a highly relevant and achievable goal. The barriers primarily involve the high upfront capital investment and the challenges of operating electrified systems in harsh winter climates. Nonetheless, long-term benefits in reduced fuel dependence and integration with clean electricity make this a strategic pathway for Canada's passenger rail systems.

Data sensitivity - Public

Table 1 Decarbonization Strategies Analysis

Decarbonization Strategy	Implementation in Australia (Status/Impact)	Relevance to Canadian Context	Barriers in Canada
Full Electrification of Rail	Ongoing in major urban areas (e.g., Sydney Metro); moderate emissions reduction	High for passenger corridors in Ontario and Quebec	High infrastructure cost and weather challenges
Hydrogen-powered Trains	Pilot projects in Queensland; high potential for regional use	Very high potential in vast rural networks	Hydrogen production and distribution limitations
Battery-electric Trains	Limited deployment; suitable for light-rail and urban systems	Moderate; requires infrastructure alignment	Battery range and cold weather performance

A second strategy, hydrogen-powered trains, has emerged as a promising solution in regional and rural areas of Australia, with pilot programs underway in Queensland and South Australia. Hydrogen trains, particularly when powered by green hydrogen from renewable sources, offer an alternative to electrification in areas where installing overhead wires is impractical. Canada's vast geography and decentralized rail network make hydrogen a highly applicable technology, especially in the Prairies and Northern regions. However, significant challenges remain in hydrogen production, storage, and distribution, which would require cross-sector coordination and sustained government support. The advantage of hydrogen systems lies in their scalability and the ability to leverage Canada's growing renewable energy sector.

Battery-electric trains, though limited in deployment in Australia, have shown effectiveness in light-rail and short-haul urban routes. Their low noise, zero local emissions, and potential integration with smart grid systems make them an attractive option for intra-city mobility. In Canada, battery-electric systems could be piloted in cities like Vancouver, Toronto, or Ottawa. However, concerns around battery range and degradation in cold climates remain critical barriers. Research and development efforts focusing on battery performance in sub-zero conditions could unlock this potential in the Canadian context.

Another area of focus is the adoption of renewable diesel in freight operations. In Australia, trials using biodiesel blends have shown moderate emission reductions without the need for major engine modifications. For Canada's freight-dominated railway sector, particularly Class I operators like CN and CP, this offers a transitional pathway with relatively low capital risk. However, renewable diesel supply chains are currently underdeveloped in Canada, requiring investment in biofuel production and logistics infrastructure. Moreover, long-term reliance on biofuels may conflict with land-use concerns and feedstock sustainability, making it suitable as a short-to-medium-term solution.

Public-private partnerships (PPPs) have played a crucial role in advancing rail decarbonization in Australia. Joint ventures between state governments and global manufacturers have enabled the deployment of innovative technologies while spreading financial risk. For example, partnerships with companies like Alstom and CAF have resulted in the delivery of electric and hybrid trains under long-term service agreements. Canada, with its strong public infrastructure investment tradition, can benefit from adopting similar models. PPPs can enhance project viability by ensuring long-term returns for

investors and operational efficiency for public entities. The challenge lies in harmonizing federal and provincial policies and aligning procurement cycles with technological readiness.

Finally, the incorporation of green procurement policies has emerged as a strategic enabler of decarbonization in Australia. By embedding environmental performance standards into public tenders for rolling stock, governments can shape markets and incentivize manufacturers to innovate. New South Wales, for instance, includes life-cycle emissions assessments in contract evaluations. In Canada, procurement practices remain fragmented, with few unified emission criteria across provinces. Developing a national framework for low-carbon rail procurement could be instrumental in creating demand certainty and accelerating technology deployment.

Taken together, these six strategies reflect a multifaceted approach to rail decarbonization that goes beyond technological substitution. They involve systemic thinking, policy alignment, stakeholder engagement, and economic restructuring. Table 1 presents a comparative summary of each strategy, its implementation status in Australia, relevance to Canada, and major barriers.
The analysis also suggests that no single strategy can fully decarbonize the rail sector; instead, a hybrid approach is required, combining electrification in high-density corridors, hydrogen in rural and long-distance routes, and renewable fuels as transitional solutions. Canada, like Australia, must balance technological ambition with pragmatic infrastructure planning and regional equity.

Moreover, the role of regulatory certainty and long-term planning is a recurrent theme in the Australian case. Decarbonization projects have been most successful when embedded within long-term transportation and climate strategies that transcend political cycles. For Canada, the recently announced Net-Zero Emissions Accountability Act and associated climate plans offer a window of opportunity to integrate rail policy into national decarbonization efforts. Clear, measurable targets for emissions reductions in the rail sector, backed by investment and legislation, are essential to mobilize action across jurisdictions.

Another emerging insight is the value of innovation ecosystems in accelerating rail transformation. In Australia, the co-location of research institutes, rolling stock manufacturers, and clean energy providers has created hubs of experimentation and learning. Similar ecosystems could be developed in Canadian provinces with existing rail expertise—such as Ontario and Quebec—through targeted funding and public-private research consortia.

Finally, social acceptance and workforce development are critical to the success of any decarbonization initiative. In Australia, early engagement with rail unions and training programs for new technologies have reduced resistance and facilitated smoother implementation. Canada, facing an aging rail workforce and labor shortages, must prioritize training programs, transition supports, and community engagement as part of its decarbonization roadmap.

In conclusion, Australia's efforts to decarbonize its rolling stock provide a valuable and diverse set of experiences for Canada. While geographic, institutional, and energy system differences must be considered, the overarching principles of system integration, multi-technology deployment, and stakeholder alignment remain highly relevant. The table of strategies above not only summarizes key findings but also serves as a strategic blueprint for policymakers, engineers, and investors in the Canadian context. A successful transition to low-carbon rail in Canada will depend on the ability to adapt these lessons into a coherent, long-term, and inclusive national strategy.

Table 2 Comparative Analysis of Decarbonization Strategies in Australia's Rail Sector and Their Relevance to Canada

Decarbonization Strategy	Implementation in Australia (Status/Impact)	Relevance to Canadian Context	Barriers in Canada
Full Electrification of Rail	Ongoing in major urban areas (e.g., Sydney Metro); moderate emissions reduction	High for passenger corridors in Ontario and Quebec	High infrastructure cost and weather challenges
Hydrogen-powered Trains	Pilot projects in Queensland; high potential for regional use	Very high potential in vast rural networks	Hydrogen production and distribution limitations
Battery-electric Trains	Limited deployment; suitable for light-rail and urban systems	Moderate; requires infrastructure alignment	Battery range and cold weather performance
Renewable Diesel Adoption	Tested in freight corridors; moderate cost-effective impact	High feasibility in freight-heavy routes	Limited renewable diesel supply chains
Public-Private Partnerships	Widely used in NSW and Victoria; accelerated innovation	High; model can be adopted across provinces	Policy alignment across federal and provincial levels
Green Procurement Policies	Adopted in rolling stock tenders; fosters market for green tech	Strategic; helps shape long-term procurement	Lack of unified emission criteria in procurement

Fiqure1 Relevance of Australian Decarbonization Strategies to the Canadian Railway Sector

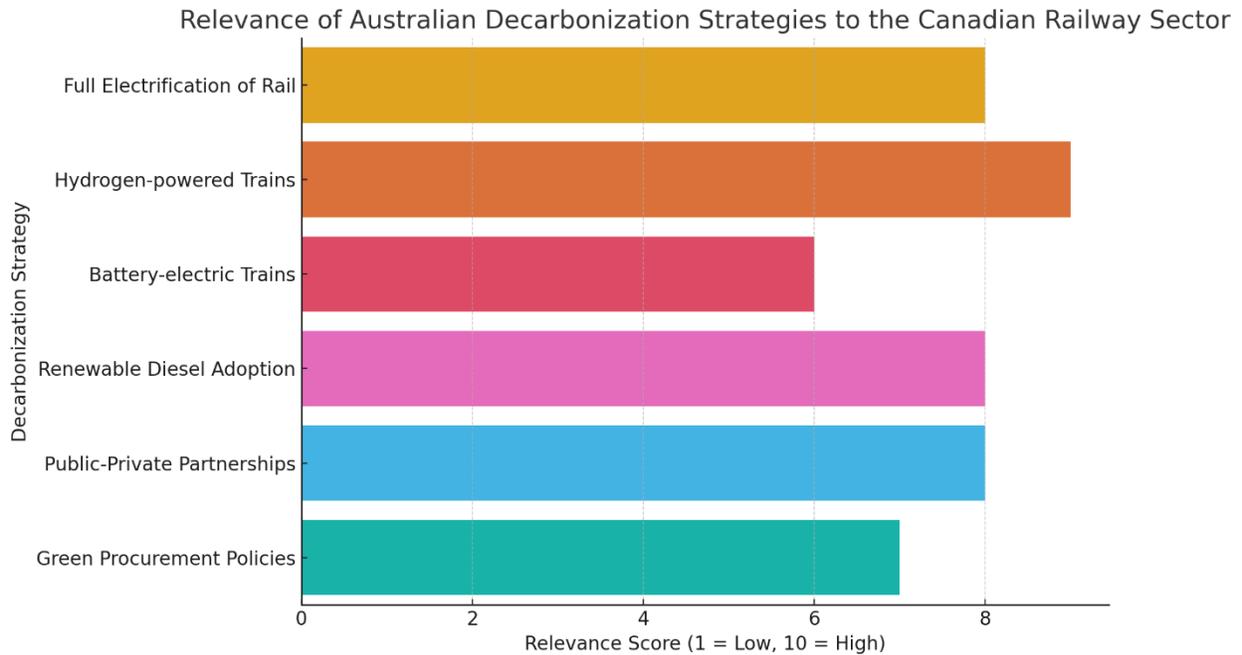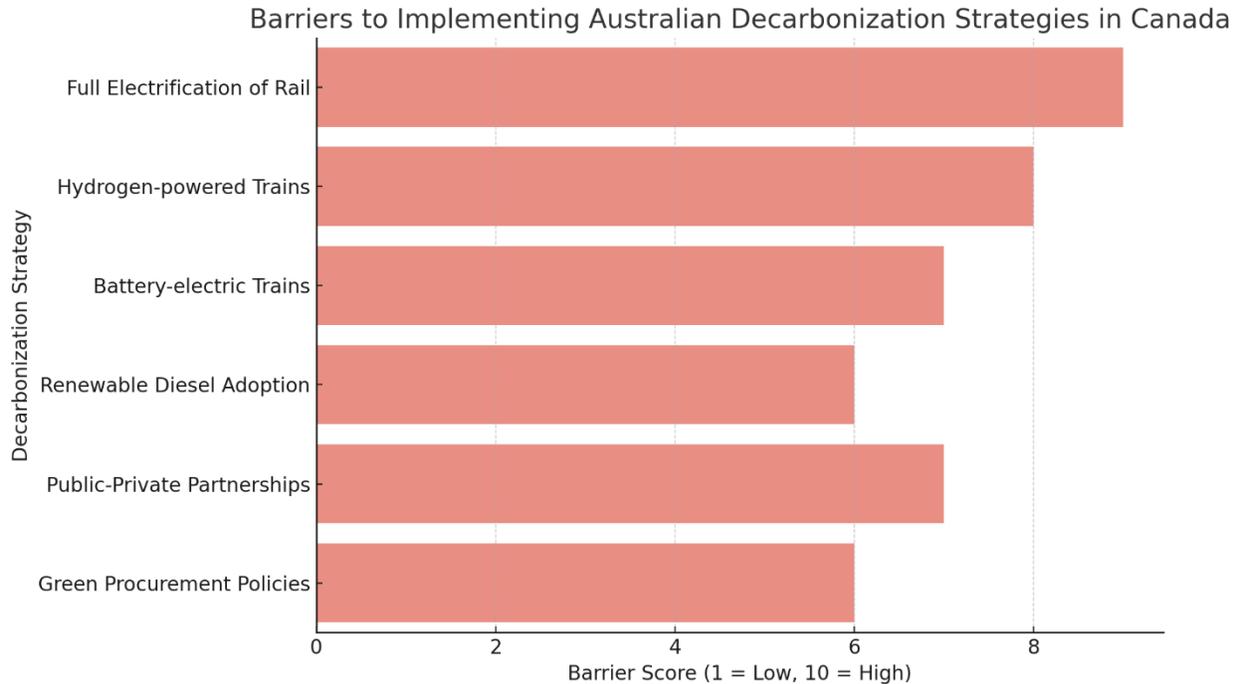Fiqure2 Barriers to Implementing Australian Decarbonization Strategies in Canada

Barriers to Implementing Australian Decarbonization Strategies in Canada

The comparative table and the accompanying charts provide a detailed snapshot of how various decarbonization strategies, successfully explored or implemented in Australia, align with the needs, challenges, and conditions of the Canadian railway sector. The table outlines six key strategies—ranging from full electrification to hydrogen-powered trains and green procurement policies—evaluating their current implementation status in Australia, their applicability to the Canadian context, and the main barriers hindering their potential adaptation.

The relevance chart shows that hydrogen-powered trains scored the highest (9 out of 10) in terms of applicability to Canada. This is largely due to Canada's expansive rural and low-density rail corridors, which are logistically unsuited to full electrification but offer great potential for hydrogen integration, especially if green hydrogen production is expanded. Full electrification, renewable diesel adoption, and public-private partnerships also ranked highly (score of 8), especially for corridors in Ontario and Quebec, where passenger rail density and grid access make electrification viable. Battery-electric trains scored moderately (6) due to concerns regarding battery performance in extreme cold, a recurring issue in Canadian winters. Green procurement, although strategic, ranked slightly lower (7) due to the current lack of unified emission standards in Canadian procurement protocols.

The barrier chart reflects a reversed trend, where the strategies that are most relevant tend to face higher implementation challenges. Full electrification, for instance, scored 9 in terms of barriers, reflecting the immense infrastructure costs, geographic scale, and operational complications associated with electrifying long rail corridors in a cold climate. Hydrogen-powered trains scored 8 on the barrier scale, mostly due to limited hydrogen distribution networks and production capacities. Battery-electric trains, although promising, face technical challenges related to battery degradation in sub-zero temperatures and limited travel range, reflected in a barrier score of 7. Public-private partnerships and renewable diesel both scored 6–7, indicating moderate barriers mostly related to policy coordination and supply chain readiness.

Overall, the charts emphasize a classic tension in infrastructure policy—strategies that are most effective or promising often come with higher technical and economic hurdles. This suggests that Canada must prioritize a hybrid strategy, investing in low-barrier, high-reward solutions for immediate gains (such as renewable diesel in freight and pilot-scale hydrogen applications) while gradually building out the infrastructure and institutional frameworks necessary for large-scale electrification and system-wide transformation. The insights from Australia's experience, when contextualized through this comparative lens, provide a practical roadmap for Canada's decarbonization journey.

5. Conclusion

The transition toward decarbonized rail systems is an essential component of broader national efforts to meet climate targets and modernize transportation infrastructure. This study, through a comprehensive review of Australia's decarbonization strategies in the railway sector, has identified a range of policies, technologies, and institutional mechanisms that offer valuable insights for Canada's evolving rail landscape. Despite contextual differences between the two countries, including geography, energy markets, and institutional frameworks, several key lessons emerge that are adaptable and actionable. Australia's progress in electrifying urban rail lines, piloting hydrogen-powered trains, and investing in renewable energy infrastructure highlights the importance of integrating clean technology with long-term planning and stakeholder coordination. These strategies have not only reduced operational emissions but have also driven innovation in procurement, workforce development, and inter-agency collaboration. Canada's rail sector, which is largely reliant on diesel, especially for freight transportation across vast distances, faces a more complex challenge. Nevertheless, this complexity also offers an opportunity to apply tailored strategies based on regional needs, resource availability, and economic feasibility.

Among the most transferable lessons is the role of policy alignment and regulatory certainty. Australia's success in launching zero-emission rail pilots and large-scale procurement programs is closely linked to clear climate goals and integrated transport policies. For Canada to follow a similar path, there must be coordination across federal, provincial, and municipal levels to set unified standards, incentivize green innovation, and secure long-term funding mechanisms. The development of a national decarbonization roadmap for the rail sector, aligned with Canada's Net-Zero Emissions Accountability Act, would be a strong starting point.

Technologically, hydrogen-powered trains and renewable diesel offer realistic near-to-medium-term options for Canada's freight and rural rail services, where electrification is currently cost-prohibitive. Meanwhile, battery-electric and fully electrified systems can be prioritized in urban and high-density corridors. The successful deployment of such technologies in Australia shows that even partial adoption, when supported by strategic partnerships and public-private investment models, can generate momentum for broader transformation.

Another key insight is the importance of green procurement and innovation ecosystems. Australia's shift toward emissions-based criteria in rolling stock contracts has stimulated market demand for low-carbon solutions. If Canada adopts similar procurement reforms, it could catalyze domestic manufacturing of clean rail technologies, strengthen its green economy, and foster competitiveness in global transportation innovation.

In conclusion, Australia's experience demonstrates that decarbonizing rolling stock is not solely a technical challenge, but a systemic transformation involving governance, finance, technology, and social engagement. For Canada, the path forward requires a multipronged strategy that incorporates immediate, feasible actions with long-term planning and infrastructure development. By leveraging the lessons from Australia, Canada can accelerate its rail decarbonization efforts, reduce its carbon footprint, and contribute meaningfully to global climate commitments while enhancing the sustainability and resilience of its national transport system.

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