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Best practice in urban transport decarbonisation: a case study of three initiatives in Brisbane

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ABSTRACT

Avoiding the worst impacts of climate change requires a transition to net-zero greenhouse gas emissions by mid-century, if not before. Urban transport systems are a significant contributor to emissions, so effective mitigation strategies for this sector are needed. This paper starts by outlining a best practice framework for transport decarbonisation based upon a review of the international research literature that entails: shifting passengers to net-zero or low-emission modes; investing in more energy-efficient technology options; and managing the demand for transport through a combination of land-use planning and socioeconomic policies. This best practice framework is then applied to a case study conducted in Brisbane (Australia) to see how the gap between the concepts developed in the research literature and the practice of making a change may be bridged. A policy analysis of three key transport initiatives in the city was undertaken to determine how they measure up against the best practice framework. On the positive side, Brisbane has the advantage of providing a reasonably reliable public transport system, expanding its bicycle/walking paths and engaging local communities in the decision-making and implementation. However, Brisbane faces a high degree of urban sprawl and car dependency, exacerbating its ecological footprint.

Key Points:

- Urban transport is not sustainable and needs to be decarbonised. This requires a framework of practical solutions to assist transport planners and policymakers in moving towards a more sustainable, low-emission future.
- The best practice framework for transport decarbonisation entails shifting commuters to low-emission transport options, investing in more energy-efficient vehicles, and managing the demand for transport.
- Brisbane has geographically extensive and reasonably reliable public transport systems and community engagement processes, but the city is challenged by urban sprawl and car dependency.

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1. Introduction

Population growth and an increasingly globalised economy have increased the movement of people and goods, which makes the goal of reducing energy consumption and greenhouse gas (GHG) emissions from the transport sector challenging (Banister, Schwanen, and Anable 2012; Banister 2011; Butterfield and Low 2017; Wimbadi, Djalante, and Mori 2021). Transport is the second largest energy-consuming sector, and it contributes to socio-economic development, increased urbanisation, land use change, and demographic changes (IPCC 2022a).

International commitments to combat climate change and reduce global GHG emissions are increasing. National governments committed to limiting global warming to 1.5°C above pre-industrial levels under the Paris Agreement, and at the Conference of the Parties (COP) 26 in Glasgow, there was a majority commitment to reach net zero emissions by the middle of the century (Müller and Reutter 2022; United Nations n.d.; United Nations Climate Change, n.d.).

The transport sector is responsible for 15% of total GHG emissions and 25% of global CO2 emissions, and passenger mobility is expected to double by 2050, so effective large-scale mitigation policies for transport are needed (IPCC 2022a; Lefèvre et al. 2021; Horschutz Nemoto et al. 2021).

Achieving sustainable mobility in urban areas will require investment in low-carbon options (Ang and Marchal 2013). Such a transition requires a transdisciplinary approach that includes deploying mixed transport options, land-use planning, behavioural economics,

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and increased renewable energy (Horschutz Nemoto et al. 2021). The idea is to develop a regime of policy/planning tools to achieve environmental, social, and economic benefits (Banister 2011; Ang and Marchal 2013).

This paper begins with an outline of a best practice framework for the decarbonisation of urban transport systems developed from a review of the international research literature. This framework is then used to assess three urban transport initiatives in Brisbane, Australia. Lastly, the set of best practice recommendations and transport behaviour in Brisbane are discussed. The paper addresses the following research questions: What is best practice in sustainable urban transport planning? How do three key urban transport initiatives in Brisbane compare to best practice? What are the barriers and enablers for improvement?

Despite significant emission reductions since the 1990s, the transport sector remains a significant contributor to GHG emissions in the State of Queensland in Australia (Rutvika and Nolan 2020). Located in the south-eastern region of Queensland, Brisbane is the third largest Australian city, with two million residents in its greater metropolitan area (Tao, Corcoran, and Mateo-Babiano 2017; Yang and Pojani 2017). As the state's capital and regional centre, Brisbane is a strategic case study for transport decarbonisation. It is the region's centre of employment and economic activities (Brisbane City Council 2018b). It also has a substantial road and rail network, and the main transport corridors for the state converge in the Central Business District (CBD) (Brisbane City Council 2018b).

A high volume of long daily trips from surrounding municipalities (such as the Gold Coast and Sunshine Coast) to central Brisbane results in long-distance travel and traffic congestion. This is the result of three different drivers in the city:

- A high degree of population growth.
- A dispersed residential population throughout an extensive urban area.
- The concentration of employment in the CBD (Yang and Pojani 2017).

The main transport policies in Brisbane are primarily designed to support population growth in the city and the region. These policies aim to achieve economic, social and environmental outcomes. The latest version of the South East Queensland (SEQ) Regional Plan, which was released in 2017, includes two priorities that are pertinent to this study:

- Building a quality public transport network.
- Promoting active transport (Queensland Government 2017b).

The main goals are to mitigate urban transport emissions and reduce regional congestion. Key initiatives are directed at an integrated planning approach, mainly through land use changes and investment in infrastructure.

This paper analyses how Brisbane follows these regional planning strategies in the Brisbane Local Government Area (LGA). Three key initiatives undertaken by the Brisbane City Council (covering road infrastructure, bus and ferry services) and the Queensland State Government (covering the rail network and major road projects) are outlined:

- The Brisbane Transport Plan, which provides general guidelines for making Brisbane's urban transport system more attractive, efficient and sustainable.
- The Cross River Rail project, that is a large-scale public transport project aiming at improving the rail network.
- The Green Bridges program, which involves land-use and urban planning to promote active mobility.

Section 2 outlines the methods used in producing this paper. Section 3 reviews the international literature to build a framework for best practice that can be used in planning and policymaking to decarbonise urban transport. Section 4 provides an overview of the strengths and weaknesses of Brisbane's urban transport systems. The following sections are focussed on policy analysis regarding the Brisbane Transport Plan, the Cross River Rail project, the Green Bridges program, and other projects. The effectiveness of these policies is assessed against the best practice framework derived from the literature review. The last section of this paper then discusses the potential of best practice recommendations to achieve net zero emissions for the coming decades and evaluates the scale of change required in transport behaviour in Brisbane to mitigate emissions.

2. Methods

In terms of the research design, first, a review of the international literature was conducted to develop a framework of best practice to mitigate GHG emissions from urban transport. This review outlined some of the literature's key debates, identified common criteria for best practice, and drew practical guidelines for policymakers and planners. The framework was then applied to a case study of three major urban transport initiatives in Brisbane (Australia). This case study selected three major initiatives to test specific examples of sustainable transport planning.

In terms of data collection, a search of peer-reviewed journal articles from the international literature was conducted using the authors' university library database, Scopus, and Google Scholar, with a date range from 2010 to 2022. The following search

terms were used: 'transport', 'mitigation', 'transport planning', 'best practice', 'emissions', 'Brisbane', 'transport demand management', 'urban commuting', 'active mobility', 'public transport', 'shared mobility', 'teleactivities', 'emission standards', 'electric transport', 'land-use planning', and 'travel behaviour'. Two key international reports were also included because of their relevance: the Global Environment Outlook 6 of the United Nations Environment Programme (2019), and the Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC 2022a, 2022b).

A total of 75 articles were initially identified as potentially useful for the literature review during the research process. The selection of articles was limited to the transport of people within urban areas by a range of modes, such as walking, cycling, public transport, motorised private vehicles, and shared mobility. The transport of goods, and modes such as ships and planes, were excluded. After filtering for relevance to the research questions, 33 articles were left. Their content was analysed against the following themes: recommendations for sustainable transport planning in cities; relevant policy instruments to achieve this transition; technological and emission standards in the transport sector; and some background information on urban transport systems. Nvivo software was used to select and organise the data collected according to these themes. A framework of best practice for urban transport was then constructed.

A policy analysis of three key transport initiatives in Brisbane was then undertaken using the literature review results. The purpose of the case study was to bridge the gap between theory and practice by identifying real-world opportunities and obstacles. Three transport policies/projects were selected for analysis based on their relevance to the research questions: the Transport Plan for Brisbane, the Cross River Rail project, and the Green Bridges Program. These offer a useful cross-section of different policy types: one was a comprehensive policy that covers all aspects of transport (i.e., the Transport Plan for Brisbane), one was a major project for public transport (i.e., the Cross River Rail), and a one was a project involving urban design and land use planning activities (i.e., the Green Bridges Program). The analysis of these plans and programs involved studying their main goals, whether the features of best practice were present or not, the actions that were implemented on the ground, the opportunities and obstacles encountered, and a policy effectiveness assessment.

The primary qualitative data sources used to conduct the Brisbane case study came from official websites and government reports, such as the Brisbane City Council, the Queensland Government, and the Australian government. Quantitative information was collected through statistical websites such as Statista and the Bureau of Infrastructure and Transport Research Economics. Peer-reviewed journal articles and research institute reports were also utilised.

This paper aims to develop a framework of best practice in sustainable urban transport planning and test it against the reality and constraints of specific examples in Brisbane. The framework could serve as a guide for future transport policymaking and planning at the city scale.

3. Best practice to decarbonise urban transport systems: a literature review

This section first uses the review of the international research literature to identify the drivers and conditions that influence sustainable transport systems. The drivers include travel behaviour, social and spatial organisation, infrastructure, and technological change. This aim is to develop a best practice framework for decarbonising urban transport systems and making them more sustainable.

3.1. A robust policy framework

The first criterion to emerge from the literature review is that planning measures should be embedded within a robust institutional framework. Developing policies and programs towards more sustainable transport systems are essential to achieving decarbonisation targets. The goals must be ambitious and prioritised and should clearly define implementation pathways in the short-term and the long-term (Wimbadi, Djalante, and Mori 2021; United Nations Environment Program 2019). These mitigation targets must also be adequate for the city's geographic, climatic, economic, and cultural context (Butterfield and Low 2017).

Polycentric governance involves policymakers coordinating different stakeholders, such as research organisations, businesses (including vehicle manufacturers), local communities, engineers, planners, and non-governmental organisations (NGOs) (United Nations Environment Program 2019). This requires sound engagement processes, including participatory decision-making and public-private partnerships, to plan future scenarios and implementation strategies (Lefèvre et al. 2021; Butterfield and Low 2017).

To evaluate the effectiveness of a policy, the United Nations Environment Program (2019) has developed a list of criteria to be achieved in the Global Environment Outlook (GEO) 6 report, as shown in Table 1. This list can serve as a model for assessing the potential of transport plans and policies in terms of effectiveness and best practice.

Table 1. Evaluation criteria for policy effectiveness. Source: United Nations Environment Program (2019).

	Evaluation criteria for policy effectiveness	
1	Effectiveness – goal achievement	What effects did the policy have on the targeted problem?
2	Unintended effects	What were the unintended effects of this policy?
3	Baseline	Was the baseline defined at the policy design stage?
4	Coherence – convergence – synergy	How does the policy intersect with other related policies?
5	Co-benefits	Did the policy design provide for co-benefits?
6	Equity – winners and losers	What are the effects of this policy on different population groups?
7	Constraining factors	What external factors are likely to influence the intended policy effects?
8	Cost – cost-effectiveness	What were the economic costs and benefits of this policy? Is it the most cost-effective or the least-cost approach?
9	Time frame	Was the policy implemented within the expected time frame?
10	Feasibility	Is the policy technically feasible in the institutional context?
11	Acceptability	Do the relevant policy stakeholders view the policy as generally acceptable?
12	Stakeholder involvement	To what extent were affected stakeholders actively involved in implementation?
13	Other factors	Intergenerational and socio-cultural effects, transboundary impacts, sociocultural concerns, compliance with legal standards

3.2. Investing in low-emission transport options

The literature suggests that investing in low to zero-emission transport options is a top priority to achieve best practice in transport decarbonisation. This mitigation strategy meets target 11.2 of the United Nations Sustainable Development Goals (SDG) from the 2030 Agenda for Sustainable Development, aiming to 'provide access to safe, affordable, accessible and sustainable transport systems for all' by 2030 (United Nations Environment Program n.d.).

The goal of redesigning urban transport is to encourage a modal shift from private motorised vehicles to more climate-friendly transport options, such as active mobility (i.e., walking and cycling) and public transport, by making them more accessible, efficient, and attractive for commuters (Tyler Miller and Spoolman 2015; McLeod, Scheurer, and Curtis 2017; Müller and Reutter 2022). This modal shift would reduce car dependency and GHG emissions. Additional co-benefits will be reduced traffic congestion and air pollution, increased efficiency, improved health, and technological improvements (Kenworthy 2018).

Promoting active mobility by developing biking and walking networks should be a high priority (Gallo and Marinelli 2020; Tyler Miller and Spoolman 2015).

The literature also argues that investing in public transport is an essential best practice option to decarbonise urban transport systems (Gallo and Marinelli 2020). By being able to move many people per trip, public transport is the easiest option to quickly address an increasing travel demand and deal with space shortages (Wimbadi, Djalante, and Mori 2021). Public transport is also energy-efficient and reduces traffic congestion and air pollution, mitigating car dependency and offsetting urban emissions (Fernandez-Sanchez and Fernandez-Heredia 2018; Kenworthy 2018; McLeod, Scheurer, and Curtis 2017).

Effective planning also involves multimodality (i.e., allowing transfers and connections with other transport options), frequent services and access to many destinations to make public transport networks attractive for commuters (Fernandez-Sanchez and Fernandez-Heredia 2018). The goal is to sufficiently increase the public transport supply to address travel demand and compete with car use (McLeod, Scheurer, and Curtis 2017).

Promoting shared mobility can also help to reduce private motorised trips and reduce the production of emissions per commuter by expanding their choice of options, but the effects of shared mobility on reducing emissions are still under debate (Lah 2019; Mouratidis, Peters, and van Wee 2021). Encouraging teleactivities can positively impact urban emissions by reducing the need to travel. But even if teleactivities became more widespread with the pandemic crisis, there is still no consensus in the literature on their ability to decarbonise transport systems as they can generate additional trips thanks to the time saved (Mouratidis, Peters, and van Wee 2021; Giovanis 2018). In a nutshell, shared mobility and teleactivities can be considered worthy of consideration as best practice options to achieve a sustainable transport planning transition. However, they cannot be a substitute for other mitigation strategies.

3.3. Emission and performance standards improvements on conventional vehicles

The literature suggests that despite strategic planning interventions to reduce car reliance, car use is unlikely to be totally eliminated from urban mobility. Best practice strategies must encourage technological change in vehicles to eliminate pollutants, such as CO2, methane, particulates, and aerosols as well as reducing energy intensity (Müller and Reutter 2022; Lefèvre et al. 2021; Ku, Kammen, and Castellanos 2021). Policy interventions can use regulations to reduce emissions and improve vehicle design (Obaid, Torok, and Ortega 2021). This can involve permit programs, inspections, audits, or emissions monitoring (United Nations Environment Program 2019).

Another key solution to mitigating car emissions is investing in electric vehicles (EVs) in the automotive market (Nanaki and Koroneos 2016). Although EVs emit indirect emissions during production, they are still considered zero-emission vehicles in terms of use. The need to replace carbon-fueled vehicles with EVs is widely recognised as a promising mitigation strategy (Obaid, Torok, and Ortega 2021; Kenworthy 2018). EVs remain expensive to purchase today for low-income households (Ku, Kammen, and Castellanos 2021) but the literature predicts declining future prices due to expanding mass production in China (Hsieh, Pan, and Green 2020).

In addition to electricity, alternative fuels can be introduced into the vehicle fleet, such as hydrogen. These strategies are still emerging, and research is growing to find the most suitable fuel system (Gallo and Marinelli 2020).

3.4. Transport demand management

The literature also offers findings on demand-side solutions to decarbonise urban transport systems that involve social, economic and spatial changes. These require a transport demand management approach and organisational changes (Black and Schreffler 2010; Lefèvre et al. 2021). This approach involves the provision of transport supply that better suits the needs of commuters (i.e., location, route, time of travel, transport option) and changing travel behaviour, such as the need to travel or modal shifts (Shubenkova and Makarova 2018; Banister 2011; Black and Schreffler 2010). Reducing travel demand through urban and transport planning are promising mitigation strategies that complement the best practice framework for transport decarbonisation (IPCC 2022b). This involves socio-economic measures and coordinated plans and policies at a systemic level (Black and Schreffler 2010; Makarova, Shubenkova, and Pashkevich 2021).

Land-use planning and smart growth policies can play a decisive role in mitigating urban transport emissions because housing densities and the spatial distribution of transport routes and infrastructure directly impact the origin, destination, and choice of travel (Holz-Rau and Scheiner 2019). Polycentric urban design and comprehensive smart growth policies, such as mixed-used zoning, transit-oriented development (TODs), and increasing urban densities around mass-transit routes, are best practice solutions that reduce urban sprawl, travel demand, and traffic congestion (Tyler Miller and Spoolman 2015; Banister 2011; Dulal, Brodnig, and Onoriose 2011; Eckelman 2013). TODs aim to co-locate population and jobs around important public transport stations and invest in public transport networks to make them polycentric and multi-destination (Kenworthy 2018; McLeod, Scheurer, and Curtis 2017).

These strategies follow the compact city approach, aiming at increasing urban density to reduce travel demand and, therefore, GHG emissions. There is a consensus within the literature that compact cities encourage mass transit transport options and reduce car use and travel distances (Dulal, Brodnig, and Onoriose 2011; Banister 2011). The goal is not to ban car use but to design urban areas so that residents do not need to use cars to commute, as mass transit transport services are easily accessible (Banister 2011).

Behavioural economics is also a mitigation strategy to influence travel demand. It is essential for influencing commuter choices towards more climate-friendly travel options (Dulal, Brodnig, and Onoriose 2011). This can be done through the introduction of a tax on petrol to discourage car use and accelerate modal shifts towards lower-emission transport options or more energy-efficient vehicles (Tyler Miller and Spoolman 2015). Congestion charges during peak traffic hours, the pricing of parking, or financial incentives for purchasing low-polluting vehicles are good examples (Gallo and Marinelli 2020).

Finally, integrating social factors into planning strategies is also an essential component to consider. This can be done by ensuring that transport services remain affordable, convenient, and accessible, especially for low-income neighbourhoods (Grieco 2015; Gallo and Marinelli 2020).

3.5. Synthesis

Overall the international research literature suggests that a framework of best practice to reduce GHG emissions and improve sustainability in urban transport systems entails: a robust policy/planning framework; shifting passengers to net-zero or low-emission modes; investing in more energy-efficient technology options; and, managing the demand for transport through a combination of land-use policies planning and socioeconomic measures. These are synthesised into a set of criteria in Table 2.

4. Overview of Brisbane's transport systems

The best practice framework will now be applied to the specific local context of Brisbane to analyse the effectiveness of key policies and plans for the city. Figure 1 gives an overview of Brisbane's transport systems by illustrating the city's main centres of activity and transport corridors, including road and rail networks.

4.1. Major transport plans

The key plans for the Queensland and Brisbane region that set the stage for the transport system are focussed on infrastructure and urban planning but also set out the framework for implementing transport planning

Table 2. Synthesis of best practice in decarbonising urban transport systems and mitigating emissions.

Synthesis of best practice in decarbonising urban transport systems and mitigating emissions		
	Mitigation option	Examples of measures
1	Develop policy and planning programs toward more sustainable transport systems	Introduce new national or international agreements with more ambitious targets Improve public information on these programs
2	Include multi-level stakeholders in the decision-making and implementation process	Develop participatory approaches, forums, and public-private partnerships
3	Shape cities towards transport-oriented developments and higher density zones	Increase residential and employment densities around mass-transit routes Develop mixed-use zoning plans
4	Promote an equitable spatial distribution of transport resources	Make transport stations easily accessible for low-income and suburban neighbourhoods
5	Encourage modal shift to low-emission travel modes through behavioural economics	Increase taxes on gasoline, parking fees and controls, congestion pricing and incentives for the purchase of low-polluting travel modes
6	Develop walking and biking networks	Construction of pedestrian and cycle areas Construction of safety infrastructure Develop bike-sharing systems
7	Invest in public transport systems to make them more efficient and attractive	Invest in rail and bus systems in terms of technology, infrastructure, frequency and quality of services, transfers, and number of destinations
8	Promote shared mobility	Create dedicated parking stations for shared vehicles (bikes, cars) Develop mobile applications to facilitate user access to shared mobility
9	Make teleactivities more widespread, especially telecommuting	Improve ICTs to support and facilitate their development
10	Invest in electric and hybrid travel options	Construct additional electric buses and trains Introduce subsidies to support the market Improve communication to encourage the purchase of electric/hybrid vehicles
11	Promote the use of cleaner fuels in the vehicle fleet	Reduce production costs Introduce subsidies for biofuels, natural gas, and hydrogen
12	Strengthen emission and performance standards on conventional vehicles	Implement emission limits on the production process regarding polluting industrial processes, equipment, and products

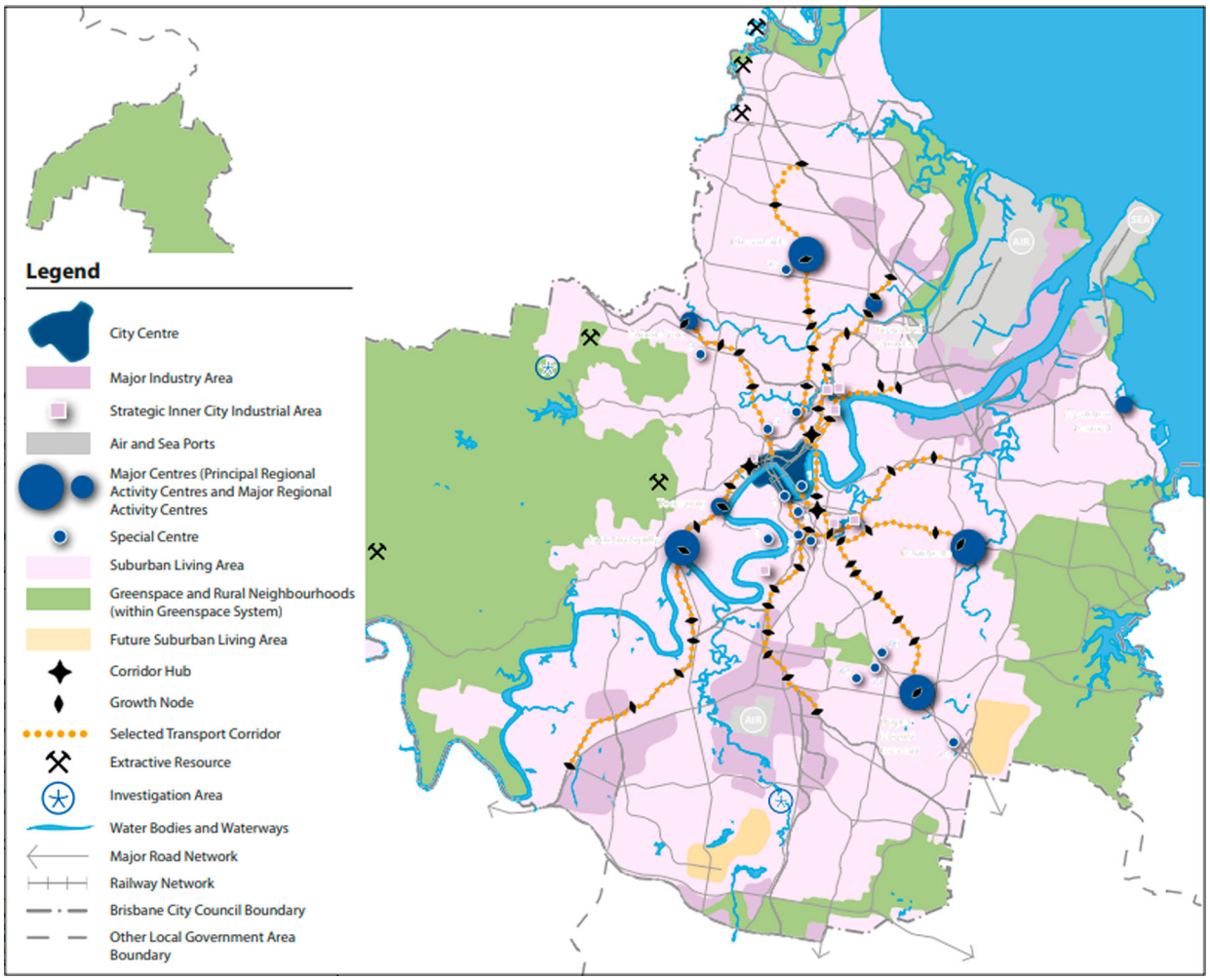

Figure 1. Land Use Strategic Framework Map of Brisbane. Source: Brisbane City Council (2018b).

in Brisbane. They highlight the city's directions to improve and decarbonise its transport network.

4.1.1. Queensland scale – state infrastructure plan

The State Infrastructure plan aims to provide guidelines for infrastructure planning and investment in Queensland through partnerships between the state government, local governments and the private sector. The objectives focus on developing jobs, growth and productivity across regions and precincts, improving urban sustainability and resilience, and adopting innovative approaches to development issues. For transport infrastructure, priorities are set on reducing transport emissions, developing the SEQ rail network, incentivising low and zero-emission transport options, and preparing for the 2032 Olympic games (Queensland Government 2021).

4.1.2. South-East Queensland scale – SEQ Regional Plan

In the SEQ Regional Plan, the two priorities in transport planning are improving the quality of the public transport system, including services and infrastructure, and promoting active transport. To achieve this, integrated planning approaches are used through the following key actions:

- Infrastructure investments.
- Digitalisation solutions to reduce the need for travel.
- Implementing more TODs to promote active mobility and public transport around key employment nodes (Queensland Government 2017b).

Table 3 summarises the relevant transport-related action plans and priorities the SEQ Regional Plan set.

4.1.3. Brisbane scale – Brisbane City Plan

The latest Brisbane City Plan, introduced in 2014, provides guidelines on land-use development and infrastructure planning for the city. The main goals are supporting population growth and developing urban neighbourhoods (Brisbane City Council 2021a). The strategic outcomes for transport and infrastructure are supporting a competitive economy, enhancing the quality of life, and improving infrastructure environmental performance. These goals follow the results of the Brisbane Transport Plan and involve three implementation priorities:

- Providing efficient and reliable travel options to improve access for commuters to jobs, services, and business and industries' activities.
- Meeting the needs and demands of transport users, including equitable access for disadvantaged groups and easy access to events or tourist activities.
- Mitigating transport emissions through the increased use of active transport (Brisbane City Council 2014).

4.1.4. Brisbane scale – Local Government Infrastructure Plan

The Local Government Infrastructure Plan is part of the implementation framework of the Brisbane City Plan 2014 for urban infrastructure. This includes approximately 1000 projects in transport, stormwater infrastructure, parks, and land-based facilities. In terms of transport infrastructure, the Local Government Infrastructure Plan supports the creation and upgrade of roads, including bridges and green bridges, pedestrian and cycle pathways, dedicated bus lanes, and ferry terminals (Brisbane City Council 2021f).

4.2. Key strengths of Brisbane's transport systems

4.2.1. Public transport: successful bus systems and an expansive rail network

The primary strength of Brisbane's transport systems is the success and efficiency of its public transport network, especially bus services. Brisbane City Council is the largest funder of public transport of any city council in Australia (Queensland Government 2017a; Yen et al. 2018).

Coordinated by the Translink agency, Brisbane bus services are efficient and high-quality (Yang and Pojani 2017; Tao, Corcoran, and Mateo-Babiano 2017). They are considered fast, comfortable, cost-

Table 3. Priorities in planning strategies from the South-East Queensland Regional Plan to decarbonise transport in South-East Queensland. Source: Queensland Government (2017b).

Priorities in planning strategies to decarbonise transport in South-East Queensland		
1	An efficient movement system	Efficient use of existing infrastructure and cost-effective upgrade or expansion of infrastructure networks
2	Active transport	Greater use where higher density development and key employment nodes are supported by high-frequency public transport of active and public transport
3	Integrated planning	Infrastructure and land use planning and delivery are integrated
4	Prioritised infrastructure investment	Support infrastructure solutions to provide an adequate, accessible, and affordable urban land supply
5	Regional infrastructure networks	Ensure land use and built form support the efficient use of current and future regional infrastructure networks, in a sustainable, cost-effective and timely manner
6	Digital infrastructure	Support digital networks that enable transactions and data flow across the economy, and reduce the need for travel

effective, and frequent. They also run on dedicated busways (the South East Busway, the Northern Busway, and the Eastern Busway), separated from other traffic, called 'quick-ways' (Tao, Corcoran, and Mateo-Babiano 2017; Yen et al. 2018). These 'quick-ways' help ease urban traffic congestion. Brisbane city's bus network has over 400 routes and 10,000 stations, operates around 260 buses during peak hours, and involves 54% of all public transport trips (the remaining part comprising mostly rail transport) (Tao, Corcoran, and Mateo-Babiano 2017).

The rail network is not operated by the Brisbane City Council but by a division of the Queensland Government, the CityRail network. Rail systems are not as developed as bus networks in Brisbane. However, investments in more rail stations and lines are increasing. The SEQ rail network has over 200 km of lines and connects Brisbane to the Sunshine Coast and the Gold Coast; although the Sunshine Coast and the Gold Coast are separate cities, they also function as outer suburbs of Brisbane, with people commuting from them to the CBD. Brisbane's rail network comprises eight lines connecting the CBD (Yen et al. 2018).

Brisbane also has a network of river ferries with 24 terminals and three lines (CityCat, CityHopper and CityFerries), operating from The University of Queensland at St Lucia to Northshore Hamilton (Yen et al. 2018; Brisbane City Council 2022d). As the Brisbane river cuts across the city, the ferry network is an important transport option for encouraging inner city density and promoting river-oriented mixed-use activities (Yang and Pojani 2017).

Brisbane's public transport network is CBD-oriented, where the core bus and rail networks are concentrated in the CBD (Yen et al. 2018). The city is ambitious to extend the network further out to provide more efficient interchange points, improve transport accessibility for the suburbs and decongest the CBD. Rail and bus networks are complementary, with trains usually covering long distances and buses being more widespread over short to medium distances through the inner city (Queensland Government 2017a).

Historically, investment in transport was primarily directed to road infrastructure rather than public transport. Significant investments in public transport are relatively recent and have been more directed to improving operations and services than new infrastructure. But projections for the next four years call for major rail and bus infrastructure investments to increase transport supply (Queensland Government 2017a).

4.2.2. Active mobility: a well-developed cycle path network

Active mobility is one of the City Council's key strategies for making its transport systems more sustainable. The action plan is to provide an extensive network of walking and cycling paths to improve access in specific locations and ease congestion (Rutvika and Nolan 2020). In the Brisbane Active Transport Strategy 2012–26, the following targets have been set:

- Achieving a transport modal share of 15% walking and 5% cycling by 2026.
- Building a 1700 km bikeway by 2031 (Brisbane City Council 2022b).

Brisbane has a well-developed cycling network, and efforts have been made to provide a significant amount of cycle and walking paths across the city, with many of them separated from the road (Cycling Brisbane n.d.b.; Brisbane City Council 2022a). The primary desired outcomes are providing more active travel paths and improving safety and connectivity for pedestrians and cyclists (Brisbane City Council 2022b).

4.2.3. Land-use planning: a large volume of TODs

Another strength of Brisbane's transport systems, which meets best practice, is the effort to develop TODs throughout the city. Coordination between local governments and private developers led to TOD projects in targeted growth areas (Yang and Pojani 2017). TODs are mainly concentrated near the city centre; a few transit-oriented regions are also in the suburbs (Kamruzzaman, Deilami, and Yigitcanlar 2018). With the Brisbane City Plan, densification and urban development policies are underway in inner city suburbs such as West End, New Farm and Tenerife. These include additional residential areas and mixed-use developments around transport nodes (Brisbane City Council 2014).

To address Brisbane's urban sprawl issues, specific transit-oriented areas have been defined in the city to promote self-contained activities. These areas are designed around a combination of public transport options, including rail, buses and ferries. Brisbane's TOD developments result in high residential and employment density areas, with fast and frequent public transport services (Kamruzzaman, Deilami, and Yigitcanlar 2018).

4.3. Key weaknesses of Brisbane's transport systems

4.3.1. Low urban density and high ecological footprint

Brisbane has a very low population density, with an average of 18 people per hectare (Spencer, Gill, and Schmahmann 2015). The city also faces significant problems of urban sprawl and a large ecological footprint. Indeed, the Queensland region (of which

Brisbane is the principal city) is the most significant contributor to GHG emissions, accounting for over 30% of Australia's emissions, while only 20.4% of the country's population lives in the region (Australian Government 2021; Hughes 2022). Urban sprawl is considered a significant barrier to sustainable outcomes in the transport field as it leads to an intense car dependency.

4.3.2. A strong car dependency

Along with the Queensland region (and many other Australian cities), private vehicle ownership and use are predominant in Brisbane. Nearly 80% of households own a car, and 85% of daily trips are made by personal motorised vehicles in the city (Tao, Corcoran, and Mateo-Babiano 2017). Car dependency is even stronger in the suburbs, where employment hubs and frequent public transport services are less present (Yang and Pojani 2017).

Despite well-developed and high-quality services, public transport use remains low (13.7%) (Brisbane City Council 2018b). Despite the expansion of bicycle networks, the modal share is even lower for active mobility, with only 4% of Greater Brisbane residents using this mode of transport to get to work (Rutvika and Nolan 2020).

The main reasons for Brisbane's heavy reliance on cars are urban sprawl and travel behaviour. Car dependency historically comes from the long economic boom after World War II, where the rise of standards of living, population growth, urban sprawl, and low price of petrol made car use widespread across cities in Australia (Bureau of Infrastructure and Transport Research Economics 2014).

In addition, past transport investments were focused on road infrastructure, making car use more convenient (Queensland Government 2017a). This extensive road network does not encourage a modal shift to lower-emission transport options. For example, it can create barriers to the use of active transport. A survey conducted by Rutvika, M. K. and Nolan, R. in 2020 outlined the main obstacles to cycling in Queensland, which are the following:

- Unsafe road conditions.
- Speed/volume of traffic.
- Lack of bicycle lanes.
- Weather conditions.
- Destinations too far away.
- Too hilly (Rutvika and Nolan 2020).

These barriers can be applied to the Brisbane case study as the city is characterised by a humid subtropical climate, hilly roads, and a high volume of road traffic.

4.3.3. High travel demand and congestion issues

Key transport policies for Brisbane's future are designed to address population and employment growth, which are expected to exceed transport capacity in the coming years. The population in inner Brisbane is expected to increase by 4% per year (Queensland Government 2017a). In addition, employment growth in the SEQ region will be primarily concentrated in Brisbane, increasing the number of people commuting into the city (Australian Government 2017). These two drivers result in a high travel demand, which is expected to be strengthened even more in the future and involves transport capacity constraints.

Brisbane is already facing congestion issues, causing an annual cost of $2 billion. This cost is expected to reach $4.1 to $5.6 billion by 2030 (Queensland Government 2017a). Brisbane roads are already at their capacity, and the issue will get worse with population and employment growth. In addition to increasing emissions, congestion also affects bus services that use public roads by causing delays (Queensland Government 2017a).

Areas of congestion are primarily concentrated in the CBD during peak periods and around cross-river bridges. Despite an extensive road network, the city faces a lack of river crossings, with a total of only 16 bridges, which increases congestion (Brisbane City Council 2021a; Brisbane Australia n.d.). The M1 motorway connecting Brisbane to Logan and the Gold Coast is another example of a road overcrowded with traffic. To ease the M1 motorway's traffic congestion, additional highway projects are underway, such as the Coomera Connector (AFPG, n.d.).

4.3.4. A lack of transport electrification, despite some initiatives

As Brisbane is prone to high car dependency and includes an extensive road network, introducing subsidies for EV purchases and charging infrastructure could help to mitigate urban emissions (if the electricity is generated from clean energy sources). In Brisbane and the Queensland region, transport electrification policies are very recent.

No subsidies or public investment for EV development had been made in Queensland before the Queensland Zero Emission Vehicle Strategy 2022–2032 (ZEV). Since March 2022, however, EV buyers with a price up to $58,000 can benefit from a $3000 rebate (Queensland Government 2022). But only six models of EVs are currently cheaper than $58,000 (Business News Australia 2022). Nevertheless, the region's public investment in charging infrastructure only began this year through partnerships between local governments and private industries (Queensland Government 2022b). As these policies are relatively

new, the positive effects on climate change mitigation are not yet evident.

EVs and charging infrastructure are not yet widespread in Brisbane. Only two charging stations are available to the public in the city, at Brisbane King George Square Car Park and Bracken Ridge Library (Brisbane City Council 2022e). Most buses still run on petrol or natural gas. The only existing electric bus line to date is the City Loop, introduced in June 2021 and comprising four buses (Moore 2021).

Despite the recent initiatives undertaken to electrify transport systems, there is still a long way to go to reach the goal of zero emissions from road transport, as the city and region are only at the beginning of transition planning. Given the high car dependency, more efforts are needed to mainstream EVs for both private vehicles and public transport.

4.3.5. Climate vulnerability

The final weakness to note is the city's climate vulnerability. Brisbane has become prone to significant flooding on almost a decadal basis, with a risk of a higher frequency due to climate change. The most recent floods in 2022 highly impacted Brisbane transport systems. During the floods, most public transport services and many roads were closed. Several months later, ferry services and bikeways remained closed due to ongoing flood repairs (Brisbane City Council 2022a, 2022c). Urban transport systems in Brisbane have low resilience to climate change, making them highly vulnerable to extreme weather events.

To increase the resilience of cities to climate change and extreme weather events, the Queensland Government is committed to helping coastal councils develop adaptation strategies through the QCoast2100 program. This program is designed to support and fund council actions to address current and future risks of coastal hazards to infrastructure (including transport infrastructure), communities and the environment (QCoast2100, n.d.). Adaptation measures have been implemented in Brisbane under the Coastal Hazard Adaptation Strategy in bay side suburbs such as Brighton and Sandgate, and commercial hubs such as Brisbane CBD, to address coastal hazards and tidal inundations (Brisbane City Council 2021d).

4.4. Synthesis

The main strengths and weaknesses of Brisbane's urban transport systems have been summarised in Table 4.

5. The transport plan for Brisbane

The Transport Plan for Brisbane was published in October 2018 by Brisbane City Council to provide guidelines for the city's transport network over the next 25 years (Brisbane City Council 2018b). The

Table 4. Synthesis of the strengths and weaknesses of Brisbane urban transport systems.

Strengths		
	Criteria of best practice met	Criteria of policy effectiveness met
A large volume of TODs	Shape cities towards transport-oriented developments and higher density zones	Effectiveness – goal achievement: Reduce car use and respond to a high transport demand Co-benefits: GHG emissions reduction, reduced need for travel, higher rate of public transport use and active mobility
Successful bus systems and an expansive rail network	Invest in public transport systems to make them more efficient and attractive	Effectiveness – goal achievement: Effective public transport systems Co-benefits: GHG emissions reduction, less car use, reduced road congestion Equity: Improved accessibility for the suburbs with the Cross River Rail project Baseline: Baseline defined at the policy design stage (address employment and population growth) Cost-effectiveness: Public transport is one of the most economical means of transport
A well-developed cycle path network	Develop walking and biking networks	Co-benefits: health improvements, less car use, improved safety for cyclists and pedestrians Time frame: Rise of cycle paths over the last years Constraining factors: A need for active transport to safely coexist with car-based road infrastructure
Weaknesses		
	Criteria of policy effectiveness failed	
Low urban density and strong car dependency	Effectiveness – goal achievement: High rate of urban emissions due to urban sprawl and car dependency, low rate of public transport and active transport modal share Unintended effects: Closure of riverside lanes, urban density and transport strikes increased congestion	
High travel demand and congestion issues	Effectiveness – goal achievement: Congestion increases GHG emissions and negatively impacts transport systems' effectiveness Feasibility: Difficulties to ease congestion in the inner city due to increasing travel demand to be expected with population and employment growth	
A lack of transport electrification	Effectiveness – Goal achievement: Electric vehicles' ownership and charging infrastructure are not yet widespread in the city	
Climate vulnerability	Effectiveness – goal achievement: Low resilience of Brisbane's transport systems to climate change Unintended effects: Closure of roads, public transport services, and cycling/walking pathways with floods	

Transport Plan includes decarbonisation strategies. Four desired outcomes are stated in this policy:

- Enhancing liveability.
- Delivering economic benefits.
- Harnessing innovation.
- Evolving the network (Brisbane City Council 2022f).

These goals are expressed as a set of eighty strategic directions intended to guide transport decision-making in the city (Brisbane City Council 2018b). Improving the attractiveness of sustainable transport options, investing in TODs through land use and infrastructure, or managing road congestion are relevant measures highlighted by the Transport Plan (Brisbane City Council 2022f). This policy's main objective is to decarbonise the transport sector and improve the effectiveness and efficiency of transport systems and the quality of transport services and infrastructure.

The Council released a second document entitled 'The Transport Plan for Brisbane – Implementation Plan 2018' to support these strategic directions. This document details the Council's implementation frameworks regarding transport planning, provision, management, and operations (Brisbane City Council 2022f).

The Council coordinates various actions between SEQ local governments, transport authorities, the private sector, research partners and the community (Brisbane City Council 2018a). In addition to coordinating the Transport Plan's initiatives among these different organisations, the Council also monitors and evaluates their progress over time (Brisbane City Council 2018a). These initiatives are undertaken through the Council plans and programs detailed in Table 5.

The main priorities are to promote active mobility, shared mobility and public transport and to invest in innovation. The need for efficient management of road networks and infrastructure to address congestion and improved and safer road sharing between all modes of transport (private vehicles, pedestrians, cyclists, buses) are also priorities.

Table 6 reviews the key initiatives implemented through the Transport Plan, and Table 7 outlines which key initiatives of the Transport Plan meet best practice criteria. Each initiative outlined in Table 7 appears to meet best practice criteria, except for the motorcycling category. Indeed, although motorcycles can be an alternative to cars to reduce congestion, they remain a polluting mode of transport and do not encourage a modal shift to more sustainable transport options. This initiative refers to the paradox of the city promoting eco-friendly modes of transport while developing its road network in favour of private motorised vehicles.

Table 5. Council plans, programs and activities following the outcomes of the Transport Plan. Source: Brisbane City Council (2018a).

Council plans, programs and activities following the outcomes of the Transport Plan
Brisbane City Plan 2014 (including Neighbourhood Plans and Local Government Infrastructure Plan)
Brisbane Economic Development Plan 2012–2031
Brisbane Long Term Infrastructure Plan 2012–2031
Brisbane. Clean, Green, Sustainable 2017–2031
Brisbane Active Transport Strategy 2012–2026
Brisbane Access and Inclusion Plan 2012–2017
River's Edge Strategy Brisbane's Inner-City River Activation Strategy 2013
Local laws
Transport network plans and corridor studies
Active travel programs
Congestion reduction management

6. The cross river rail project

Expanding public transport is one of the Brisbane Transport Plan's top priorities. Although Brisbane's transport investments were initially mainly focused on road infrastructure, the city is now allocating an increasing budget to public transport (Queensland Government 2017a). Investing in public transport is part of best practice recommendations to decarbonise urban transport systems.

As bus systems are well-developed in Brisbane compared to the rail network, investments are privileged towards rail lines and infrastructure. This strategy aims to address the two following issues:

- Increasing travel demand due to population growth, especially in the inner city.
- A limited rail network capacity (Cross River Rail n.d.b..).

Travel demand is expected to exceed the rail network capacity of Brisbane's CBD in the late 2020s-early 2030s (Australian Government 2017). The CBD has indeed only four inner-city stations and two rail lines. But these two lines connect with five other lines from the south and west and six from the north. This configuration limits train paths through the CBD, complicates operations, and slows the entire network (Queensland Government 2017a; Australian Government 2021; Cross River Rail, n.d.c.).

To increase the rail network's capacity and facilitate employment growth, the Cross River Rail (CRR) project is undertaken by the Queensland State Government. The CRR project creates an additional 10.2-kilometre rail line in Brisbane, from Dutton Park to Bowen Hills. This rail line includes 5.9 kilometres of twin tunnels under the Brisbane River and the CBD and four new underground stations at Boggo Road, Woolloongabba, Albert Street and Roma Street (Figure 2). Eight existing stations are also planned to be upgraded under the project (Salisbury, Rocklea,

Table 6. Summary of the Transport Plan's key implementation initiatives. Source: Brisbane City Council (2018a).

Key initiatives in implementing the Transport Plan	
	Scope of implementation
Walkable Brisbane	Develop plans for pedestrians in high-activity areas, major facilities, and local schools Identify barriers to walking and improve the infrastructure supporting pedestrian mobility Develop and implement targeted car-free days in strategic locations Encourage walking through information, education, and behaviour change programs
Green bridges	Study the feasibility and preferred route for new green brides Incorporate new bridge crossings in the active and public transport networks Work with the Australian and Queensland Governments to develop the business case for investments in an expanded green bridge network
E-wheeling (power-assisted options such as e-bikes and motorised scooters)	Provide e-wheeling options in the planning and design of shared path transport networks Work with businesses to encourage the provision of secure storage and charging facilities Monitor safety and raise awareness towards the community on appropriate behaviour and conduct on pathways
Efficient networks	Collect data on transport network use, travel behaviours and peak congestion Identify and quantify major congestion points on Brisbane's transport networks Develop new methods to manage transport more efficiently Develop and implement efficiency initiatives for key transport corridors Monitor and measure the impacts and benefits of these initiatives
Motorcycling	Promote motorcycling for commuter trips to manage road congestion and reduce the need for car parking Improve motorcycling safety in Brisbane
Brisbane's transport innovation and research hub	Undertake partnerships between the Council, government, industry, research partners and private sector to: - Seek opportunities for transport innovation and research in Brisbane - Facilitate market-based innovative solutions
Smart intersections and corridors	Expand and refine the Council's road network intelligent transport systems Identify network operational functions and locations where smart technology could improve network performance Research and test innovative approaches to transport networks and adopt ideas to improve their accessibility and sustainability Collect data and monitor impacts on corridor and intersection performance
Shared transport	Support the use of shared mobility for vulnerable groups Provide shared transport options around important public transport hubs to support the first and last mile of travel
Inner city transport network plan	Identify the impacts of future developments and infrastructure (Brisbane Metro and Cross River Rail) on the inner-city transport network, including pedestrian, cycling, public transport and road networks
Connecting Brisbane – Public Transport Plan	Undertake a partnership between the Council and the Australian and Queensland Governments to develop an integrated public transport network for Brisbane, based on the Connecting Brisbane Public Transport Plan
On-road bus priority	Identify, assess, and monitor on-road bus priority measures such as bus jumps and traffic signal modifications
Move Safe Brisbane	Develop an integrated transport safety plan for Brisbane for all transport modes and users Develop short, medium and long-term targets to reduce transport-related incidents and accidents Identify potential security and safety improvements around public transport hubs
Safe travel together	Improve cycling safety technologies such as sensors and cameras Raise awareness to heavy vehicle and bus industries on cyclist vulnerability and encourage safe cycling practices when sharing the road Work with key stakeholders to identify transport infrastructure planning, design and operational improvements to foster safe road sharing Identify and prioritise locations for safety improvements based on recorded accident data, stakeholder information and community feedback

Moorooka, Yeerongpilly, Yeronga, Fairfield, Dutton Park, and Exhibition) (Australian Government 2021; Cross River Rail n.d.b.).

The CRR plans to achieve a various range of desired outcomes. First, the project will decongest bus systems and increase the rail network's capacity through the

Table 7. Best practice features involved in the Transport Plan's key initiatives.

Transport Plan key initiatives	Best practice outcomes
Walkable Brisbane	Encourage modal shift to low-emission travel modes through behavioural economics Develop walking and biking networks
Green bridges	Develop policy and planning programs toward more sustainable transport systems Include multi-level stakeholders in the decision-making and implementation process
E-wheeling	Include multi-level stakeholders in the decision-making and implementation process
Efficient networks	Shape cities towards transport-oriented developments
Brisbane's transport innovation and research hub	Include multi-level stakeholders in the decision-making and implementation process
Shared transport	Promote an equitable spatial distribution of transport resources Promote shared mobility
Connecting Brisbane – Public Transport Plan	Include multi-level stakeholders in the decision-making and implementation process Invest in public transport systems to make them more efficient and attractive

Figure 2. Cross River Rail network plan. Source: Australian Government (2021).

CBD by providing alternative commuting routes (Australian Government 2021). Second, this additional rail supply will help relieve congestion on bus systems in the CBD and ensure greater complementarity between rail and bus networks (Queensland Government 2017a).

This increased capacity will improve the attractiveness of public transport systems with frequent rail services and encourage a modal shift towards low-emission transport options. With the introduction of the CRR, 18,000 additional seats are expected to be available in Brisbane transport systems during morning peak usage. The project will also reduce the number of road users by providing better transport options with these new train stations. According to the Queensland State Government, 47,000 car users across South East Queensland will use trains instead of cars by 2036 once the CRR operates (Cross River Rail n.d.b.).

The CRR project will also contribute to creating new TODs (Queensland Government 2017a). The Queensland State Government has announced a future $20 billion investment in urban renewal around these new station areas to foster economic growth and create new employment hubs for the next decades (Cross River Rail n.d.b.). In a nutshell, the CRR is a relevant example to show how expanding urban public transport networks can create various co-benefits for the city.

Despite the wide range of benefits the CRR could provide, some downsides are evident. First, there is a lack of communication on quantifying the benefits. The CRR total cost is estimated at $5.4 billion (Queensland Government 2017a). However, there has been some controversy about the lack of transparency in allocating these costs. The Queensland Audit Office declared unable to reveal the cost details of the projects to the public due to commercial sensitivities (Parnell 2021).

Consequently, there is a gap between the benefits promised by the Queensland State Government and the quantification of these benefits, as shown in Table 8. In addition, the CRR is experiencing some construction delays. The project was initially expected to operate in 2024, but it has been announced that it will not be open to the public until mid-2025 (Lynch 2020).

Despite these downsides, the CRR remains an important project to increase public transport modal share in Brisbane, a city with a high car dependency. Table 9 highlights the best practice outcomes achieved under the CRR project and assesses its policy effectiveness to this extent.

Table 8. The extent to which benefits and costs are incorporated and monetised in the CRR project. Source: Searle and Legacy (2019).

	Costs/benefits quantified	Costs/benefits not included
Benefits/costs prior to project completion		
Increased traffic congestion during construction		X
Net revenue losses of businesses affected during construction		X
Other costs caused during construction		X
Travel benefits/costs		
Transport reliability and network resilience benefits	X	
Station amenity benefits	X	
Active transport benefits/costs		X
Urban development benefits/costs		
Social and environmental savings from increased urban renewal potential		X
Local community benefits/costs		
Changes in access to services and amenities		X
Environmental benefits/costs		
Change in non-greenhouse gas emissions		X

7. The green bridges program

The Green Bridges program demonstrates how land-use change and urban infrastructure renewal can play a crucial role in mitigating emissions from transport in Brisbane. By definition, a green bridge allows only foot, cycle, and sometimes public transport traffic and separates bicycle and pedestrian paths from the roads (Your Dictionary, n.d). The Green Bridges program is undertaken by the City Council and plans to build four new green bridges in Brisbane, including:

- One bridge linking Kangaroo Point to the CBD.
- One bridge from Toowong to West End.
- One bridge from St Lucia to West End.
- One crossing bridge at Breakfast Creek (Brisbane City Council, n.d.).

Building new green bridges are part of the key initiatives of the Transport Plan and follow best practice recommendations as it contributes to facilitating active transport. The Brisbane City Council is committing to invest $294 million into the Green Bridges program, with funding support from the Queensland and Australian governments. Kangaroo Point is the first green bridge expected to be delivered by late 2023, followed by the Breakfast Creek bridge by early 2024. Detailed planning delivery of the Toowong and St Lucia bridges to West End is still underway (Brisbane City Council, n.d.).

This program intends to achieve the following desired outcomes:

- Creating additional green transport infrastructure in the city.
- Promoting active transport.
- Providing more river crossing transport options to Brisbane's residents.
- Improving access and connections between residential and economic activity areas (Brisbane City Council 2020a).

Table 9. Synthesis of best practice features and policy effectiveness through the Cross River Rail project.

Best practice outcomes achieved		Policy effectiveness assessment	
Invest in public transport systems to make them more efficient and attractive	Constructing new transport infrastructure with four new underground stations	Effectiveness – goal achievement Increased public transport modal share	✓
		Improved public transport services' attractiveness	✓
	Upgrading existing transport infrastructure with the rebuild of six southside stations	Reduced traffic and public transport congestion in Brisbane's CBD	✓
		Unknown effects on reducing emissions	✗
	Decongesting public transport networks in the CBD	Equity Improved accessibility to transport from the southern and northern suburbs	✓
	Delivering a second river crossing through the city	Timeframe One year delay on the project finalisation	✗
Shape cities towards transport-oriented developments and higher density zones	Creating new station precincts with mixed-use activities	Coherence and synergy The CRR intersects with policies related to the 2032 Olympic games and other transport projects and policies (e.g., Connecting Brisbane, Brisbane Metro)	✓
	Building new employment zones	Co-benefits New employment and economic development areas	✓
	Creating higher density zones in the suburbs (e.g., Woolloongabba, Boggo Road)	Costs – Cost-effectiveness Lack of communication and transparency about the real costs and benefits of the project	✗

Figure 3. Kangaroo Point Green Bridge's construction timeline. Source: Brisbane City Council (2021e).

Table 10. Mixed-use plans and activities projected for the Kangaroo Point Green Bridge. Source: Brisbane City Council (2021e).

Infrastructure	Paths
Food and beverage facilities on the bridge and its landing	Additional connections to existing footpaths in C.T. White Park
C.T. White Park improvements with a new entrance to the plaza and new landscaping	Separate bicycle and pedestrian paths, wit space for a central tree
Lift connection to the bridge deck	Shared zone on Scott Street

Public-private partnerships are being used to build these green bridges. For example, the City Council will start the Breakfast Creek Green Bridge construction in mid-2022 with the Georgiou Brady Joint Venture contractor (Brisbane City Council, n.d.). The community is also engaged in the decision-making process through consultation programs, where around 3500 people gave feedback on the early planning stages for each bridge in 2019. Following their feedback, the proposition to build the Bellbowrie Green Bridge has been discarded (Brisbane City Council, n.d.).

To provide an overview of the program's implementation framework, the Kangaroo Point green bridge is used in this section as a case study, as it is currently the most advanced project. Its construction timeline is detailed in Figure 3.

The desired outcomes are: providing better connections between Kangaroo Point, the CBD and the eastern suburbs and reducing car travel (Brisbane City Council 2021e). In addition, mixed-use zoning plans are being undertaken on and around the Kangaroo Point Green Bridge to improve the area's attractiveness and create new activities, as detailed in Table 10. These mixed-use activities on the bridge landing can be considered TODs.

The Green Bridges program is an interesting policy as it uses urban land-use planning to transform transport infrastructure. Land-use planning is a key mitigation tool to reduce emissions from the transport field, especially with the support of mixed-use activities (Tyler Miller and Spoolman 2015). Table 11 synthesises the best practice outcomes achieved with the program's implementation and assesses its policy effectiveness.

8. Other projects

This section outlines and examines the potential success of other additional projects promoting the development of low-emission transport modes within the city.

8.1. The Brisbane bikeway projects

Brisbane's bikeway projects are part of the Transport Plan for Brisbane. The main reason stated by the local government for the bikeways is the increase of a more active lifestyle, but the plan does not mention the need to lower transport emissions (Brisbane City Council 2020b). The other reason is the need to minimise traffic congestion (Lee 2021). The bikeways are divided into six areas: Brisbane wide, Central, North, South, East and West (Brisbane City Council 2020b).

The main bikeway projects are the Central Brisbane project and the North Brisbane project. The first one

Table 11. Synthesis of best practice features and policy effectiveness through deploying the Green Bridges program.

Best practice outcomes achieved		Policy effectiveness assessment	
Include multi-level stakeholders in the decision-making and implementation process	Public-private partnerships for the construction of the new bridges	Effectiveness – goal achievement More transport options are provided for active commuters	✓
		Improved accessibility for cross-river trips	✓
	Consultation programs organised within the community for their feedback at the early planning stage of each green bridge	Equity Improved accessibility to transport for the suburbs (St Lucia, Toowong, Bowen Hills)	✓
	Decongesting public transport networks in the CBD	Feasibility Addressing the lack of bridge issues in Brisbane	✓
	Delivering a second river crossing through the city	Stakeholder involvement A wide range of stakeholders actively involved in the implementation process (private sector, community)	✓
Develop walking and biking networks	Additional bicycle and pedestrian paths created Improved safety infrastructure for active transport with separated bicycle and pedestrian paths from the road	Acceptability Bellbowrie Green Bridge's construction project was rejected by the community	✗

started in 2006 and ended in 2022 (Huntington 2021b). The benefits are an increase of 143% in bike rides in the CBD since 2006 and better accessibility to workplaces (Brisbane City Council 2020b). The Citylink Cycleway trial ended in March 2022 and the new lanes were kept (Hungtinton 2021b). Nevertheless, the local government has not planned any future projects for Central Brisbane Bikeways.

The north Brisbane project started in 2016 and ended in 2021, costing 32 million dollars and increasing the bikeway rides by only 20% in 2020 (Brisbane City Council 2020b). In terms of innovation and future cycling projects in the city, there is little communication, and the City Council does not foresee any further major projects in 2023 (Brisbane City Council 2020b).

8.2. The new e-scooter program

Since the arrival of electric scooters in Brisbane in November 2018, more than four million rides have been taken by 1.4 million riders (Field and Jon 2021). With almost 5000 daily trips in Brisbane, e-mobility is a good choice for short distances, defined by the City Council as less than eight kilometres (Brisbane City Council 2021b). Due to numerous safety and traffic issues, the government has implemented extensive regulations, limiting access and speed in certain areas as well as the number of vehicles provided by local companies (Haworth, Schramm, and Twisk 2021). According to the city council, e-scooters have been the first mode of transport to return to pre-pandemic levels, showing a clear appeal to users (Brisbane City Council 2021b).

The literature shows five major advantages to e-mobility: affordability, convenience, safety, economic and sustainability (Guo and Zhang 2021; Pace et al. 2021; Brisbane City Council 2021b).

Indeed, e-scooters aim to reduce congestion and pollution by replacing car trips with electric engine vehicles, also positively impacting air quality (Severengiz et al. 2020). The future strategy of the city council is to combine the access of e-scooters within the new Metro project (Brisbane City Council 2021b). Thus, it will allow users to combine a metro ride with an e-scooter ride to work, for instance. The city council has the vocation to promote e-mobility, encourage the community and private sector to use e-mobility devices, and monitor e-mobility improvements and changes (Brisbane City Council 2021b). To do so, local governments focus on five pillars containing their own actions and outcomes: safety, accessibility, mobility, agility, and infrastructure (Field and Jon 2021; Brisbane City Council 2021b). If the city council clearly focuses on safety actions, their infrastructure actions are also important, which should guarantee a bright future for e-mobility in Brisbane (Haworth, Schramm, and Twisk 2021).

8.3. The CityCat ferry system

The CityCat ferry project was launched in 1996 and is connecting 25 places along the Brisbane River (Byrne 2020). Ferries compete with other modes of transport, such as buses (Tanko, Burke, and Yen 2019). Users largely favour faster bus trips (Tanko, Burke, and Yen 2019). However, some people prefer ferries for cultural and wellness reasons (Tanko, Burke, and Yen 2019). The Brisbane ferry system has very low resilience to extreme weather events as it was heavily impacted by flooding. In 2022, the entire river system was closed for many weeks, and it took several months to return to a quasi-normal network (Nishino et al. 2022). Even today, the network is not fully renovated and repaired. In 2023, three ferry terminals will be upgraded and a new one will be built (Brisbane City Council 2022c).

To judge the effectiveness of the ferries in relieving congestion in the city, it is necessary to look at the number of daily users and their evolution (Tanko and Burke 2015). The ferry fleet amounts to 23 vessels (Byrne 2020). However, even if there are no public statistics on the number of daily users, it seems to be low. The ferries are sometimes empty, and an extreme majority of commuters prefer faster and more direct buses (Nishino et al. 2022). The ferry network is nevertheless a significant tourist attraction.

8.4. The defunct CityCycling scheme

The CityCycle scheme, launched in 2010, was planned to operate until 2030 with the French advertising company JCDecaux (Stone 2020). But the bike-share program phased out in late 2020 with the growing success of dockless shared e-scooters (Bland, Leung, and Kaufman 2021; Brisbane City Council 2021c). The CityCycle scheme faced some criticism regarding the bike design, considered unsuitable for a hot and hilly city like Brisbane, and the stations not being evenly distributed in the city (Huntington 2021a).

Despite these weaknesses, the CityCycle has generated a growing interest in active mobility among researchers and has highlighted the need to develop shared active mobility programs to compensate for the lack of cycling culture in Australia (Huntington 2021a; Heesch and Turrell 2014). The success of e-scooters and e-bikes with Beam and Neuron as leaders has shown that there is now a growing market for shared mobility in Brisbane (Cycling Brisbane n.d.a.). But the condition for its success is its adaptability to users' needs and the city's local context (Huntington 2021a).

9. Discussion

9.1. Can best practice achieve net zero emissions?

Section 3 has identified 12 recommendations for best practice in decarbonising the urban transport sector (Table 2). Although a synthesis of the literature, these recommendations remain theoretical and do not consider the constraints on the ground. This section first defines the targets to be reached to decarbonise the transport sector adequately to limit global warming. Secondly, it will be assessed whether these objectives can be achieved in the coming decades by applying the set of best practice recommendations in the current context.

According to the IPCC's 1.5°C special report, anthropogenic global net GHG emissions must decrease by 45% from 2010 levels by 2030 and achieve net zero by 2050 to limit global warming to 1.5°C. To limit global warming by 2°C, emissions must be reduced by 25% and reach net zero by 2070 (IPCC 2022a; IPCC 2018; Lieberman 2021). In both scenarios, the IPCC argues that net zero emissions are not likely to occur in the transport sector. Consequently, negative emissions in other sectors are necessary to reach the required target ranges (IPCC 2022a).

Nevertheless, the IPCC's latest Assessment Report still calls for a major reduction of global transport emissions of respectively at least 29% and 59% by 2050 to limit global warming to 2°C and 1.5°C (IPCC 2022a). In both scenarios, priorities have been set to reach the required target ranges. These priorities follow the best practice recommendations identified in Table 2 and include major interventions in the following categories:

- Land transport, including transport infrastructure and spatial planning towards compact urban development.
- End-use technology, including more electric and energy-efficient vehicles.
- Switching transport modes within the existing network, notably towards public transport, teleworking and shared mobility (IPCC 2022a; Hoen et al. 2014).

Therefore, the 12 best practice recommendations of Table 2 are up to the task of significantly decarbonising urban transport for the next decades to come and reducing global transport emissions by at least 29% by 2050 (IPCC 2018).

However, the implementation of the 12 best practice recommendations would still not achieve net zero emissions in the transport sector due to real-world constraints and the nature of the existing network. First, the positive results of building the necessary infrastructure and influencing transport demand to decarbonise urban transport take time (Dulal, Brodnig, and Onoriose 2011). A lack of institutional and financial resources will also have a negative impact on the expected results (Macmillen and Stead 2014). Lastly, measuring the effects – by quantifying the costs and benefits- of transport behaviour changes resulting from best practice policies remains complex, due to the wide range of interactions with other socio-economic factors (Girod, van Vuuren, and de Vries 2013).

In short, net zero emissions in urban transport will not be achievable for decades, but the best practice framework can lead to significant decarbonisation of the sector. To achieve the target set by the first IPCC scenario of at least a 29% reduction in transport emissions by 2050, major investments in land transport planning, end-use technologies, and low-emission transport modes must be prioritised. The main objective is to shift global transport behaviour towards more sustainable patterns.

9.2. Transport behaviour in Brisbane: what to change

Brisbane is a relevant example of a city that needs to change the transport behaviour of its residents to meet the target of a 29% reduction in transport-related emissions by 2050. Given the current transport network, the measures currently in place will not be sufficient to meet these targets for the coming decades, and the city still has a significant margin for improvement.

Transport behaviour in Brisbane today falls far short of best practice recommendations and, if left unchanged, is highly unlikely to meet the required target ranges for transport decarbonisation. Road transport remains omnipresent in the city, where 85% of daily trips are still made by private vehicles. The use of low-emission transport modes is low, for instance, only 13.7% of passengers use public transport in the Greater Brisbane Area and electric transport is still underdeveloped, with only one electric bus line operating and only four charging stations installed in the city (Brisbane City Council 2022d; Brisbane City Council 2018b). Compact urban development and spatial planning also need improvements to address urban sprawl issues in the city.

Table 12 highlights some actions that could be implemented to change transport behaviour in Brisbane to bring passenger transport emissions within the required target ranges. The expected results of these interventions are a transformation of urban development, transport energy sources and the level of car use.

Table 12. Examples of measures to be undertaken to change transport behaviour in Brisbane and meet best practice targets.

Type of intervention	Projects/programs	Desired outcomes
Invest in rail public transport in the suburbs	Implement similar projects as the CRR in the suburbs by extending rail lines and building new transport infrastructure	Increase in public transport modal share and reduction of car use Creation of potential new TODs
Develop TODs in the suburbs	Install new pedestrian facilities and densify residential areas, shops, city services and private businesses around suburban rail stations	Increase density in the suburbs Reduced travel distances Reduced need to travel from the suburbs to the CBD Reduced urban sprawl and car dependency Improving suburban attractiveness
Reduced investment in road infrastructure	Increase in the transport budget allocated to public transport, active mobility Prioritise road investment to build additional green bridges and cycle paths Allocate more budget to public transport, active mobility, and electric transport	Limit urban sprawl, car dependency and emissions from road transport
Massively increase investment in electric transport	Renew the bus fleet towards electric buses through public-private partnerships Introduce subsidies/incentives in the automotive market for the production of electric vehicles Expand the scale of subsidies for purchasing EVs on a larger scale	Reduced emissions from road transport
	Expand the development of communication campaigns to encourage the purchase of private EVs Create additional charging stations	Increasing the energy efficiency of car use

Major Queensland and Brisbane's transport plans call for compact city development and improvements in public transport systems in their broad directions. But in reality, due to an extensive road network, the city still faces urban sprawl and car dependency remains very high, particularly in the suburbs. For instance, the modal share of private vehicles is 58.9% in the inner 5 km of Brisbane, and 72.2% in the Brisbane metropolitan area (Brisbane City Council 2018b).

Significant investment in major new road projects has been made over the past 20 years to improve accessibility in and around the city (Queensland Government 2017a) and provide better connections to major employment areas and intra-regional destinations (Brisbane City Council 2018b). Although more road investment is now directed at upgrading existing roads rather than building new ones, the budget and costs allocated to road transport by government and private organisations are larger ($22.4 billion) than all other modes of transport combined ($16.9 billion), (Brisbane City Council 2018b; Queensland Government 2017a). This extensive road network remains today the main barrier to reducing car use and creates countering effects from the initiatives following best practice recommendations, such as the CRR, Brisbane metro, or green bridges.

10. Conclusion

This paper developed a best practice framework through a review of the international research literature that entailed low-emission (walking, cycling, public transport) and energy-efficient (electric/hybrid vehicles) transport options, as well as transport demand management (land-use policies, socio-economic measures). Many drivers and conditions are necessary to achieve these best practice outcomes, including polycentric governance, firm institutional commitments, urban renewal, and technological change. This set of solutions leads to various co-benefits for the city, such as economic productivity, more efficient/attractive transport systems, and improved liveability for residents. Nevertheless, implementing this set of best practice recommendations, even simultaneously, will not be sufficient to achieve net zero emissions in urban transport for the coming decades. Negative emissions in other sectors are needed, and constraints on the ground must be considered.

The best practice framework was then applied to a real-world case study, Brisbane, to analyse the effectiveness of three existing policies and plans in the city. Brisbane is an interesting case study because of its paradoxical characteristics. The city provides a high level of policy efforts on transport planning and design to make its transport networks more attractive, efficient and sustainable. Various policies and initiatives are implemented, and increasing investments are expected in public transport and active mobility. Nevertheless, the city is subject to a subtropical climate, making it vulnerable to climate change impacts, including in the transport field.

The three initiatives analysed have met many best practice criteria, such as involving communities in the decision-making and implementation process, investing in public transport, implementing TODs and promoting active mobility. These measures have been carried out through coordination between the state government, local governments and the private sector. However, urban sprawl and car dependency prevent the city from being considered a best practice

model. As it will take a long time to correct the mistakes of the post-war period in terms of transport planning, more substantial efforts must be made to change transport behaviour, mainly by reducing reliance on cars, and, therefore, mitigating GHG emissions.

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